Anatomy and Physiology of The Eye.

Brown. Zoethout.

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The Embryology Anatomy and Histology of the Eye

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WITH ILLUSTRATIONS MADE FROM TRANSVERSE SECTIONS OF THE HUMAN EYE ENLARGED BY MICRO-PHOTOGRAPHY

The Physiology of Vision

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ILLUSTRATIONS BY THE AUTHOR

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FOREWORD.

In approaching this work, perhaps a word of explanation to the reader may be desirable. It is not undertaken because the author thinks there is a lack of knowledge about the eye; neither have there been any new facts discovered which would merit the production of these articles. It is therefore not the intention to bring out any new facts, but to put the known and widely scattered facts in a more comprehensible form and to illustrate the subject so thoroughly and completely that it will be made more easy for the beginner and more interesting to those who find it necessary to review the subject.

All the illustrations of the structures of the eyeball and smaller structures will be microphotographs taken from microscopic slides in the author's possession, while the coarser structures of the orbit will be illustrated by drawings, as these structures are too large for the tissues to be mounted on microscopic slides.

The microscopic slides used to photograph the foetal eye are from the pig and were procured at the Armour packing house by collecting the foetal pigs at the gutting table. These foetesis ran from two millimeters to forty millimeters in length, and the mounting of the slides was done by Dr. Slonaker, at the Chicago University.

The slides used in photographing the adult eye were made by Dr. Slonaker when he wrote his thesis on the acute area of vision. These slides have been used in my illustrated lectures before optical and medical societies for several years, and they have been enjoyed so much by my hearers and I have received so many requests for them in a permanent form, that it is in response to these wishes that the

author has determined to perpetuate these pictures and place them in the reach of every one who is interested in the eye; otherwise these articles would never have appeared.

A few words about the physical development of the foetus might be of benefit before the illustrations are studied. The foetus is first represented by one cell, the ovum. This is fertilized by the spermatozoa; then there is a multiplication of cells. These increase very rapidly, and the first definite form assumed is a tube, representing the worm, and this tube has two walls; one is the outer covering and the other lines the inside. The outer is known as the epiblast (meaning above) and the inner the hypoblast (meaning below). Then there is a layer developed between these two layers. This layer is known as the mesablast (meaning the middle). From the epiblast is developed the skin and nervous system. From the hypoblast is developed the alimentary canal and all the internal organs which communicate with the alimentary canal. From the middle layer, or mesoblast, is developed the connective tissue, blood vessels, muscles, bones, etc.

From the foregoing we see that in the study of the eye we are most especially concerned in the epiblast, as it forms the nervous system and therefore the brain, and the inner seat or sensory coat of the eye, and some one has well said that the eye is a part of the brain placed near the surface, back of an opening, where it may receive impressions from the external world and communicate these impressions to the main portion of the brain.

The first indication of the nervous system commences by the development of two ridges along the dorsum, or back, of the foetus during its tubular development. These are known as the neural ridges. The cells composing these ridges multiply and they rise higher and higher and finally meet above, at the center, and coalesce or grow together, leaving an opening. This is known as the neural

tube, and the whole nervous system is developed from the cells which line this tube.

Soon after the neural tube is formed, the anterior half of the foetus folds on itself, and this portion forms the brain, while the posterior, or unfolded portion, forms the spinal cord. From the anterior portion of the brain, two tubes grow out and toward the surface. These are known as the optic stalks, and they form the first step in the development of the eye.

CHAPTER I.

EMBRYOLOGY.

It might be well to explain that the major part of the embryology of the eye has been worked out from the eye of the chick and rabbit, as it is almost impossible to get fresh material in human embryos. The writer conceived the idea of going to a large packing house, where hundreds of preg-

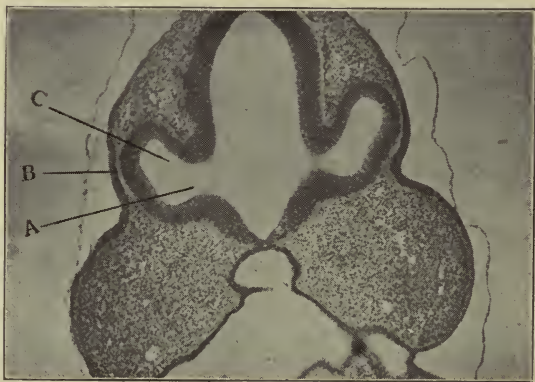

Fig. 1. Horizontal Section through Head of Foetal Pig, 2 mm. long. Magnified 3,000 times.

nant sows were gutted every day and material could be obtained fresh and in all the stages of development. This was suggested to Dr. J. Rollin Slonaker of Chicago University, and he, acting on the suggestion, procured the material and prepared the microscopic slides from which the following illustrations were made.

The first manifestation of the development of the eye is a hollow protrusion from that part of the neural tube which forms the anterior cerebral vesicle. A vesicle is an enclosed cavity, between two layers of tissue and filled with fluid, like a water blister on the hand. The neural tube, as ex-

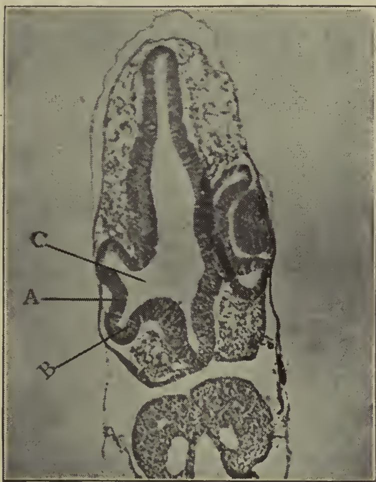

Fig. 2. Horizontal Section through Head of Unhatched Chick, 2 mm. long. Magnified 3,000 times.

plained before, is a tube developed along the dorsum or back of the foetus, during the tubular stage of development, and the whole nervous system is developed from the cells lining this tube. This hollow protrusion is known as the primary optic stalk. (See A, Fig. 1.)

As this stalk grows outward, the anterior portion rises upward, as shown in vertical section at A, Fig. 3. When the optic stalk comes near to the surface, the anterior portion enlarges, as shown at C, Fig. 1. Also when the optic stalk encroaches on the surface, it stimulates the epithelial cells forming the skin and they multiply rapidly (see B, Figs. 1 and 3), and the anterior wall of the primary optic

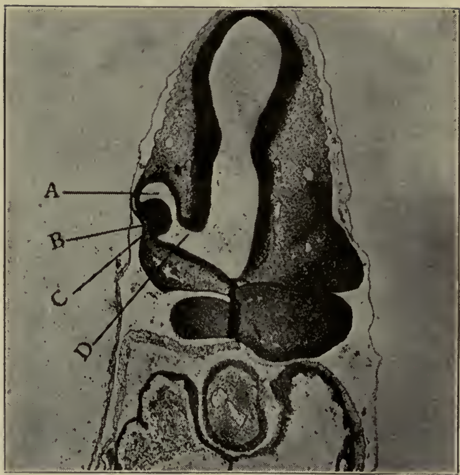

Fig. 3. Vertical Section through Head of Foetal Pig, 2 mm. long. Magnified 2,500 times.

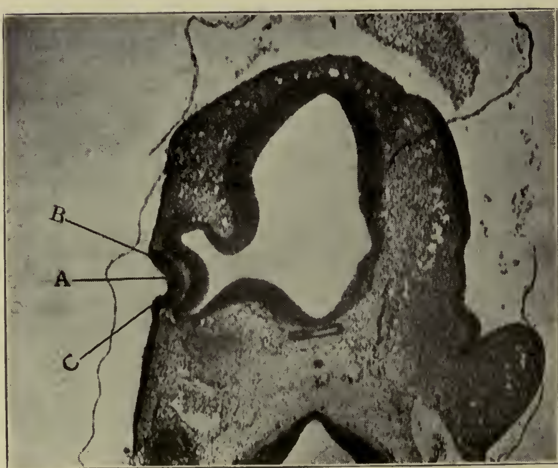

Fig. 4. Horizontal Section through Head of Foetal Pig, 3 mm. long. Magnified about 1,200 times.

vesicle invaginates and passes inside of the vesicle. (See A, Fig. 2, and C, Fig. 3.) This invagination might be likened to the denting of a hollow rubber ball.

This invaginated portion forms the secondary optic vesicle and it is from this that the nine innermost layers of the retina are eventually formed, while the primary optic vesicle only forms the outer or pigment layer. As the secondary

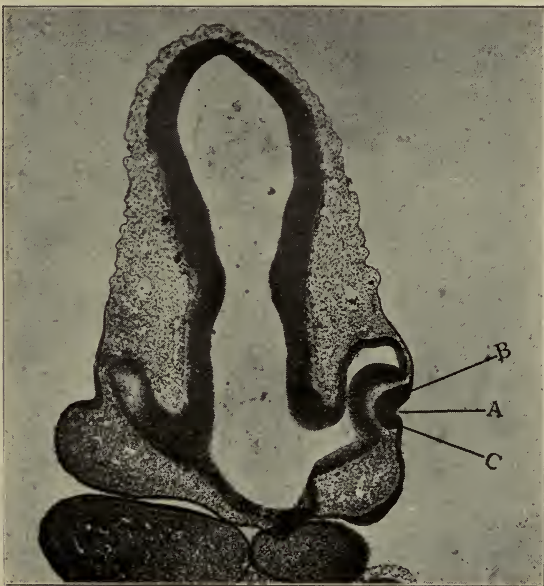

Fig. 5. Vertical Section through Head of Foetal Pig, 3 mm. long. Magnified about 2,000 times.

optic vesicle is passing into the primary optic vesicle there appears in front of the secondary optic vesicle a depression on the surface at the point of activity of the epithelial cells. (See A, Fig. 4, and A, Fig. 5.) This depression becomes deeper and deeper and the mouth is finally closed by the rapid formation of cells around the depression, as shown at B and C, Figs. 4 and 5.

Fig. 6. Vertical Section through Head of Foetal Pig, 4 mm. long. Magnified about 1,000 times.

Fig. 7. Horizontal Section through Head of Foetal Pig, 7 mm. long. Magnified about 600 times.

Thus a vesicle is formed which is known as the lens vesicle, as shown at A, Fig. 6. Then this vesicle becomes separated from the surface and passes into the secondary optic vesicle (see A, Fig. 7), and eventually forms the lens, which will be described later.

Fig. 8. Vertical section through head of pig, 8 mm. long. Magnified 460 times.

As the lens vesicle passes into the secondary optic vesicle, some of the mesoblastic cells pass upward from below, behind it (see B, Fig. 6), and it is these mesoblastic cells which will eventually multiply and form the vitreous body. It will be remembered that the mesoblast is the middle layer of the three primary layers, first formed in the foetus. The surface of the skin from which the lens vesicle was cut away remains and forms the cornea and some students of the embryology of the eye believe that the cornea owes its

transparency to the changes that take place in the nature of the epithelial cells during the formation of the lens vesicle from this immediate point. The lids are formed by an external fold, growing downward from above and upward from below the eyeball and the first indication of this growth is shown at B, Fig. 7.

Fig. 9. Horizontal section through head of pig, 9 mm. long. Magnified 460 times.

The further development of these folds is shown at A Figs. 8 and 9, also, there is a groove running from the inner side of the eye to the nasal cleft of the foėtus and the edges of this groove come together and cover in the cells at the bottom of this groove and a cord is formed from the nasal cleft to the palpebral fissure. (The palpebral fissure is the opening between the lids.) This cord divides and one branch goes to the upper lid and the other to the lower. Later there is a tube formed from this cord and this tube so formed is the lachrymal or tear duct, which runs from the palpebral fissure to the nose, and it is through this duct

that the tears are pumped from the conjunctival sack to the nose. This process will be explained later.

In Figs. 7 and 8 the lens vesicle will be seen to have been entirely separated from the surface, and at B, Fig. 8, is seen the epithelial cells which will form the outer layer of the cornea, and at C, Fig. 8, is seen the mesoblastic cells which will multiply and eventually form the four innermost layers of the cornea, the iris and other structures anterior to the lens.

At D, Fig. 8, is seen the commencement of the formation of the lens substance. This formation is accomplished by the cells of the posterior portion of the lens vesicle wall elongating and forming long spindle cells. These grow forward and fill the whole cavity of the lens vesicle, as shown at D, Fig. 9, and these extend from the anterior to the posterior limits of the cavity and are known as the lens fibers. At E, Fig. 8, is seen the opening at the posterior pole of the eye ball, where the axis cylinder processes make their escape from the eye ball, as shown at E, Fig. 9, to pass into the optic nerve as they grow from the retina toward the brain. This opening through which the optic fibers leave the eye ball is known as the choroidal fissure in the adult eye.

At F, Figs. 8 and 9, are shown the mesoblastic cells which have passed into the space between the retina and the lens. As shown at B, Fig. 6, they are just commencing to form the vitreous body, and this cavity so filled is known as the vitreous cavity in the adult eye. At G, Figs. 8 and 9, the primary optic vesicle is shown, which has become quite thin, and in the cells forming it there is being deposited pigment granules, and it will be remembered that this eventually forms the outer or pigment layer of the retina. At H, Figs. 8 and 9, will be seen the first indication of the formation of the nine innermost layers of the retina, and these nine layers are all formed from the walls of the secondary optic vesicle. There is a folding over of the optic stalk and optic vesicles, which is well illustrated by the accompanying diagrammatic drawing, Fig. 10.

A represents the primary optic vesicle; B, the secondary optic vesicle; C, the walls of the primary optic stalk, and D, the groove below the optic stalk. The lower edges of

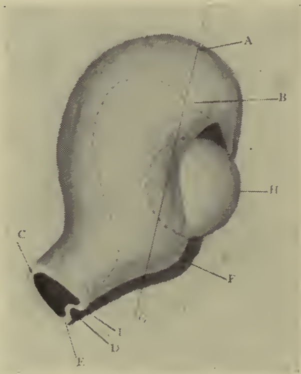

Fig. 10.

the optic stalk come together at E. and coalesce, thus forming a tube with a double wall which extends from the eye ball to the cranial cavity. This joining together takes place clear forward, along the lower part of the primary and secondary optic vesicles to F. Thus an eyeball is formed and the fissure closed is known as the choroidal fissure of the foetus. However, at the posterior of the eyeball there is an opening left, through which the axis cylinder processes leave the eyeball, E, Figs. 8 and 9. This opening is known as the choroidal fissure in the adult and corresponds to the optic disc as seen with the ophthalmoscope. It is this folding over of the embryonic structures of the eye which makes it possible for the incorporation of the arteria centralis retina (central artery of the retina) and its accompanying vein within the optic nerve for some distance back of the eye, in the adult, as this artery was already developed in the groove below the optic stalk. H, Fig. 10, represents the lens vesicle within the secondary optic vesicle. Fig. 11 represents a vertical cross section of the primary and secondary optic vesicles at about the line marked G, in Fig. 10, and A in Fig. 11 shows the primary optic vesicle wall.

B, Fig. 11, shows the secondary optic vesicle wall and C shows the choroidal fissure at the bottom of the foetal eye. D, Fig. 11, is the vitreous cavity. F, Fig. 11, is the lens vesicle cut through, and the two edges which come together and close the choroidal fissure are shown at E. When this union fails to take place we have an anomaly known as

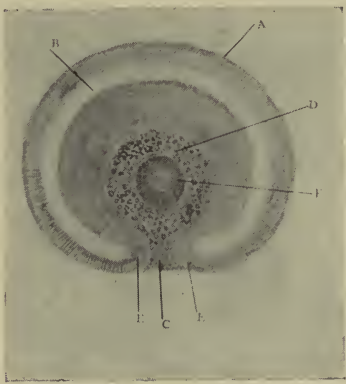

Fig. 11.

coloboma of the fundus in the adult and means a lack of development.

At A, Fig. 12, will be seen the further development of the lids; B, Fig. 12, the anterior epithehal layer of the cornea, and just beneath it is seen a lighter colored line. This is the anterior homogeneous (structureless) layer of the cornea, also known as Bowman's membrane, as he was the first to describe it. C, Fig. 12, shows the lamina propria (proper layer) of the cornea. D, Figs. 12 and 13, shows the lens fibers extending from the front to the back of the lens. These fibers are simply long spindle cells and each one has a nucleus. These form a crescent-shaped line of dots, as seen at K, Figs. 12 and 13, running from one side of the lens to the other. At J, Figs. 12 and 13, is seen the transitional (transformation) zone, and it is at this point that the lens fibers are formed, and this formation is simply the multiplication of the columnar epithelial cells, which first formed the wall of the lens vescicle and their

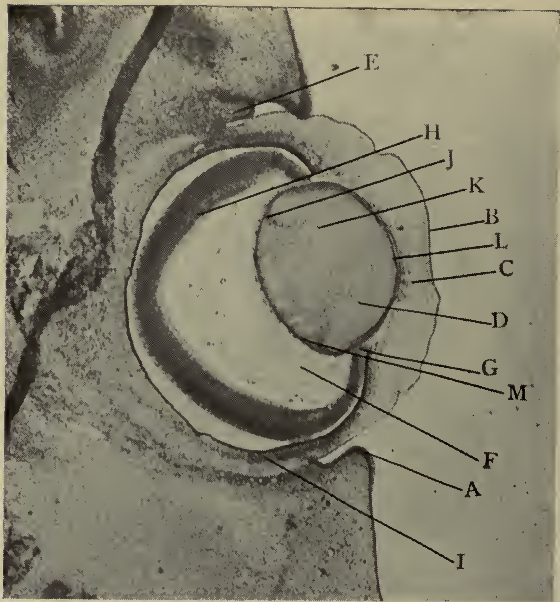

Fig. 12. Horizontal section through eye of a pig. Magnified 730 times.

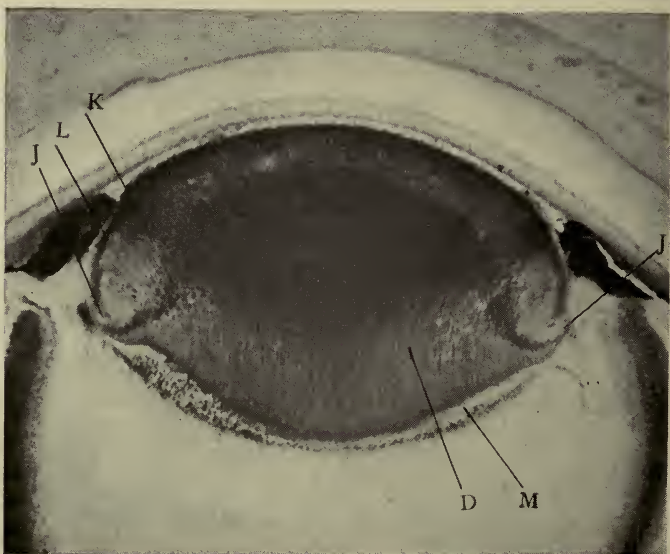

Fig. 13. Human embryo eye, 2 months. Magnified 1,080 times.

elongation into spindle cells. These spindle cells are known as the lens fibers. These fibers are especially well illustrated at D, Fig. 15, and anterior to this transitional zone where the lens fibers are formed in the adult eye will be found a single layer of the columnar epithelial cells. Underneath the capsule L, Figs. 12 and 13, and J, Fig. 16,

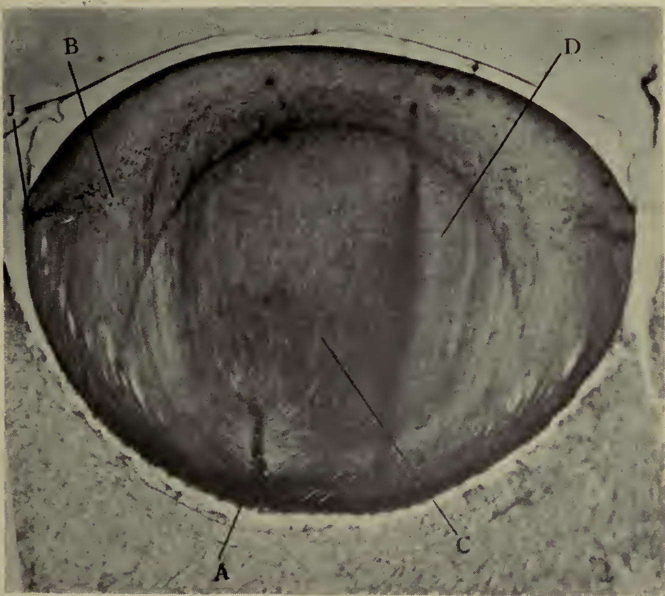

Fig. 14. Eye of embryo pig, 10 mm. long. Magnified 1,600 times.

while posterior to the transitional zone, no such cells will be found, they having elongated to form the lens fibers, as shown at D, Figs. 8 to 15.

After the lens vesicle is completely filled by fibers, extending from the front to the back of the lens in an anterior-posterior direction, as shown by the lens in Figs. 9 to 13, there is a continuation of growth of the lens by the multiplication and elongation of the columnar cells at the transitional zone, J, Figs. 12, 13 and 14. These grow forward

and backward toward the anterior and posterior poles of the lens, around the ends of the first formed fibers, and these latterly developed fibers form the soft outer or cortical portion of the lens, B, Fig. 15. While the first formed fibers constitute the nuclear or central denser portion of

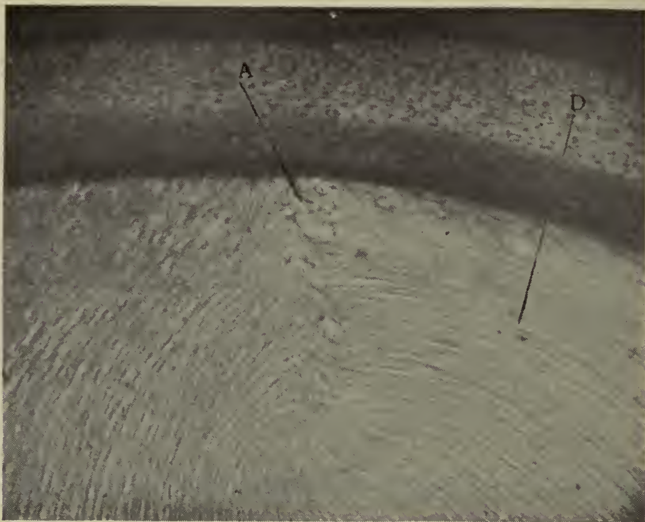

Fig. 15. Highly magnified seam from the anterior of a human embryo,

the lens, C, Fig. 14, these last formed fibers grow in such a way that when their ends come into apposition at the front and back of the lens, there are formed seams, as shown at A, Figs. 14 and 15. A, Fig. 14, is at the posterior surface of an embryo pig, and A, Fig. 15, is a more highly magnified seam from the anterior of a human embryo. These seams have a star or stilate shape, the central part being at the anterior and posterior poles and the points run outward toward the equator of the lens, and it is these seams, where the ends of the fibers in the cortical portion of the lens abut against each other, that forms the so-called

lens stars. These fibers of the lens are long, diamond-shaped, spindle cells, and these are arranged in lamella or layers and all held together by a matrix of jellatinous cement substance, and when a lens is macerated (soaked) in an alkaline solution, which will dissolve this cement substance, these lamella of the lens may be peeled off, and the best illustration is the peeling of the layers of an onion. At E, Fig. 12, is seen the commencement of the growth of the third eye lid, known as the membrana nictatans (winking membrane) in the lower animals, especially birds. This develops in man up to a certain stage, then ceases and remains as a vestige in a crescent-shaped fold near the inner side of the eye, and is called the plica semilunaris (half moon fold). At F, Fig. 12, is seen the developing vitreous body and the dark spots are the small blood vessels which furnish this body its nutrition during development. These are from the hyaloid artery, which will be described later, and these atrophy before birth. At G, Fig. 12, it will be seen that the brim or fornix at the anterior margin of the primary and secondary optic vesicles are in apposition to the capsule of the lens at its equator, and this enables some of the connective tissue, which binds the retina together, which is known as the fibers of Mueller (he being the first to discover them) to become attached to the capsule of the lens, and as the eye enlarges and the retina settles farther backward, these attached fibers elongate and thus the suspensory ligament (also known as the zonule of Zinn) is formed, and this accounts for this connection between the retina and the lens.

At H, Fig. 12, will be seen the farther development of the layers of the retina. At I, Fig. 12, are seen some cells, which are showing signs of activity. This is the first sign of the development of the choroid and sclerotic coats.

At A, Fig. 16, it will be seen that the lids are gradually covering the cornea and the membrana nictatans. E, Fig. 16, is not any farther developed than seen in Fig. 12 at E.

At B, Fig. 16, will be seen a portion of the hyaloid artery. This is an artery given off by the arteria centralis retina at the head of the optic nerve and only exists during foetal life for it atrophies before birth. It supplies the nutrition necessary for the development of the vitreous

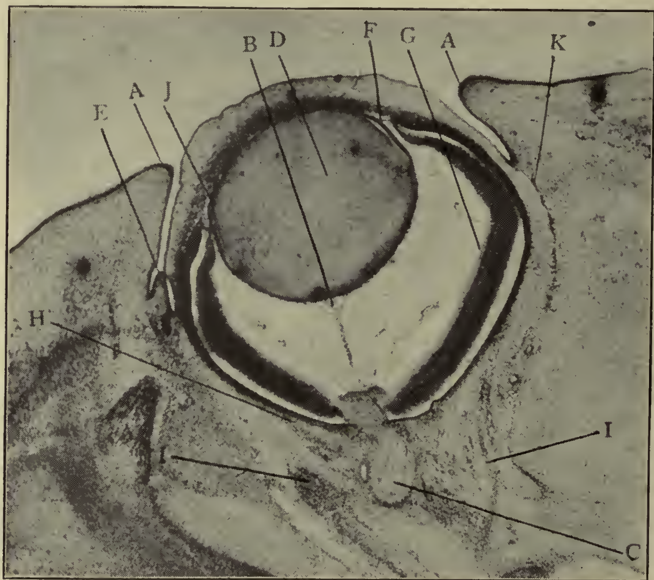

Fig. 16. Horizontal section through head of pig, 20 mm. long. Magnified 670 times.

body and the lens and when these are fully matured it atrophies and the canal through which it passed remains as a lymph channel and is known as the hyaloid canal, or the canal of Stilling, in the adult eye. The hyaloid artery, as before stated, is a branch of the arteria centralis retina and runs from the head of the optic nerve to the posterior of the lens, giving off small twigs to the developing vitreous body. At the posterior surface of the lens it

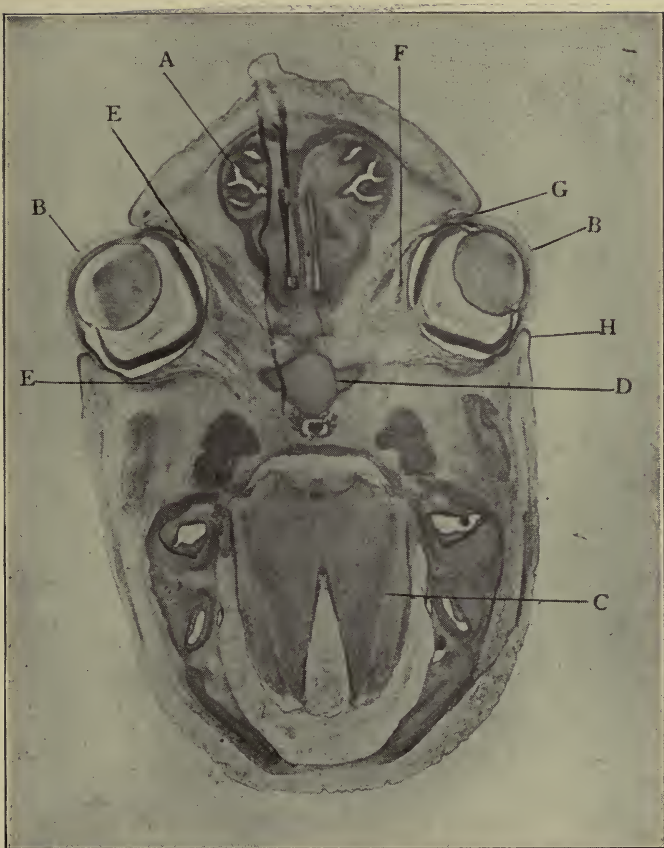

Fig. 17. Horizontal section through head of a pig, 25 mm. long. Magnified 85 times.

breaks up into several branches. These pass around the lens to the front and there come together, forming anastomoses (an anastomosis is where one vessel runs into another and continues by continuity of tissue), and the connective tissue

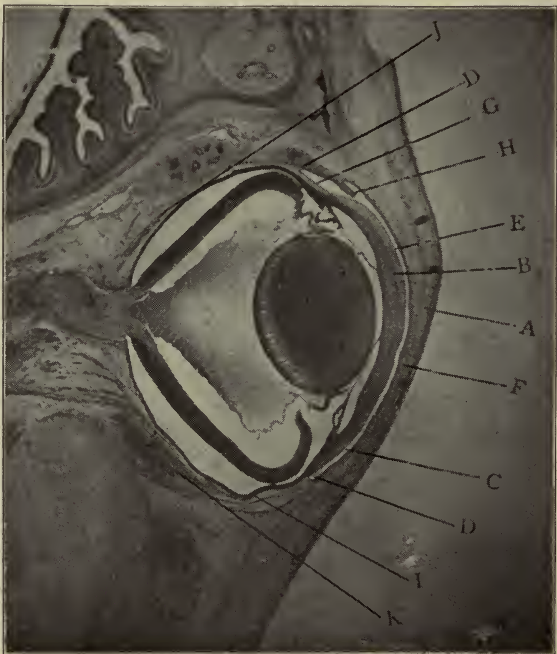

Fig. 18. Horizontal section through head of pig, 40 mm. long. Magnified 225 times.

which these vessels are imbedded in forms the pupilary membrane, which will be described later. There is a connection of these hyaloid arteries by anastomosing vessels from the front of the iris, near its free margin, with the branches of the blood vessels of the iris. This connection only exists during fœtal life.

At F, Fig. 16, is shown a band of tissue connecting the lens with the retina. This will eventually form the suspensory ligament or the Zonule of Zinn of the older writers. At H, Fig. 16, is shown the farther development of the cells

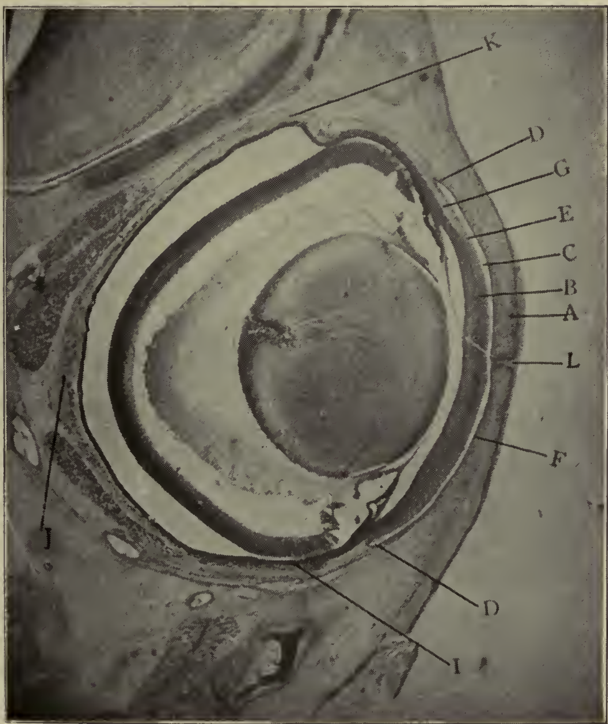

Fig. 19. Vertical section through head of pig, 40 mm. long. Magnified 320 times.

which will eventually form the choroid and sclerotic and it will be noted that they may be traçed well into the optic nerve (C, Fig. 16), at either side at the choroidal fissure, and it is these cells which will form the lamina cribrosa

(seive layer), which strengthens the eye ball at this point in the adult eye. Also C, Fig. 16, shows the first growth of the axis cylinder processes through the choroidal fissure to form the optic nerve. It must be remembered that the

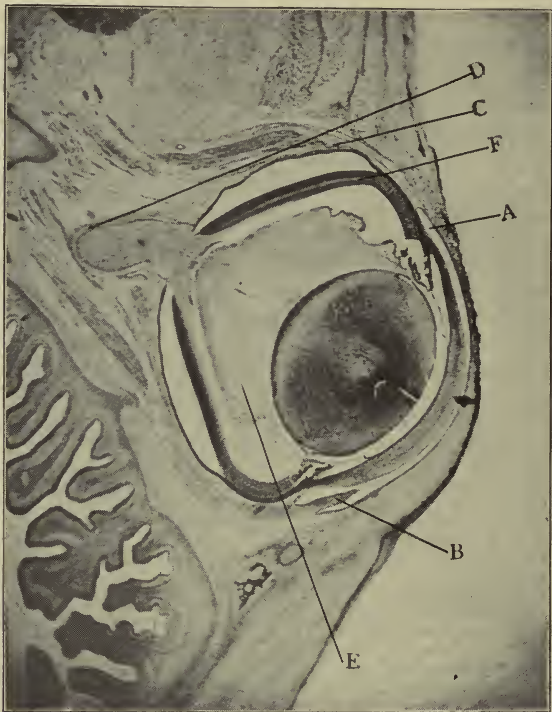

Fig. 20. Horizontal section through eye of a pig, 50 mm. long. Magnified 150 times.

fibers which transmit impulses of the sight from the retina to the brain, grow from the cells in the ganglionic layer of the retina, back toward the brain and not from the brain to the retina. At I, Fig. 16, is shown the activity of the cells, which are just commencing to form the recti (straight) or extrinsic muscles of the eye. At K, Fig. 16, will be seen a

line of small openings. This is the commencement of the space of Tenon. Fig. 17 is a horizontal section through the head of a pig, 25 M. M. long, and is shown to illustrate the rapid development of the eyes in the growth from 9 to 25 M. M. in length. A, Fig. 17, shows the nasal cavities. C, Fig. 17, shows the developing brain, and D shows the

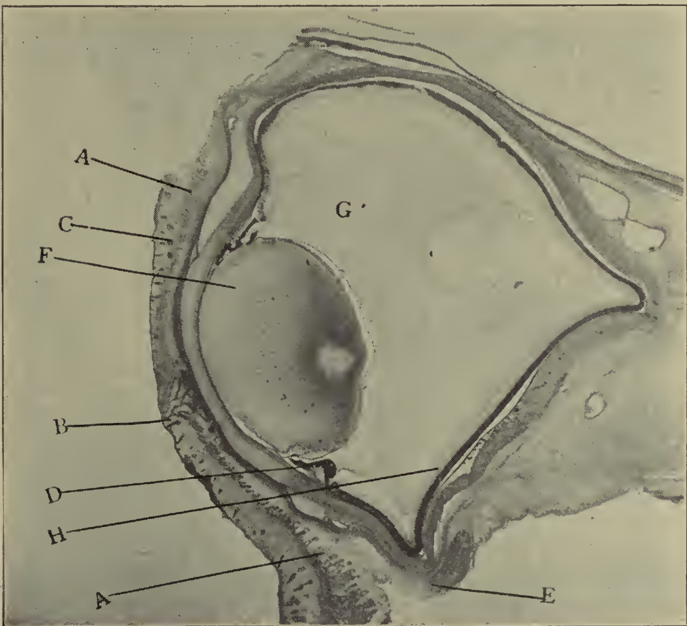

Fig. 21. Vertical section through human foetal eye at five months Magnified 120 times.

developing bone. At E is seen the farther development of the extrinsic muscles, at F is shown the farther development of the choroid and sclerotic and at G is seen the plica semilunaris and at H the lids.

At A, Figs. 18 and 19, are shown the lids entirely covering the front of the eye ball and just back of it the cornea B, and the space between the two, C, is the conjunctival sack.

The conjunctiva lines the inner surface of the lids, then folds on itself as shown at D. This is known as the Fornix (arch) conjunctiva. Then it covers all the front exposed portion of the eye ball except the cornea. The epithelial layer of the conjunctiva, continues over the cornea and forms the outermost or stratified epithelial layer of this structure, E, Figs. 18 and 19. That portion of the conjunctiva lining the lids is known as the palpebral conjunctiva, F. Figs. 18 and 19, and that portion covering the exposed scleral portion of the eye ball is known as the ocular conjunctiva, as shown at G. At H, Fig. 18, is shown the plica semilunaris, and it will be noted that it is gradually becoming smaller. At I, Figs. 18 and 19, is shown the choroid, which is just forming; at J, is shown the sclerotic and at K, Figs. 18 and 19, is shown the farther development of the extrinsic muscles.

When the two lids come into apposition in front of the eye ball they become cemented together, as shown at L. Fig. 19. In all animals in which the retina is completely developed before birth the lids are separated at birth, but in those animals whose retina is not fully developed at birth, such as the kitten and puppy, the lids do not separate for some days after birth, or until the retina is sufficiently developed so as to withstand the effects of light.

At A, Fig. 20, is shown the conjunctival sack, at B the shrinking plica semilunaris and at C the tendon of the external rectus muscle and its attachment to the eye ball in front and the belly of the muscle posteriorily. At D, Fig. 20, is shown the sheath of the optic nerve and the farther development of the nerve itself, at E the vitreous body and at F it will be seen that the retina is farther developed and about four layers may be made out.

At A, Fig. 21, is shown the developing fibers of the orbicularis (circular) palpebrarum muscle, at B is shown the margins of the lids and the developing cilia (hairs) or eye lashes, and at C is shown a developing hair in the lid. D, Fig. 21, shows the commencement of the development

of the ciliary body and the iris. These are the last structures to be developed within the eye ball. E, Fig. 21, shows the cut end of the inferior oblique muscle, F shows the lens

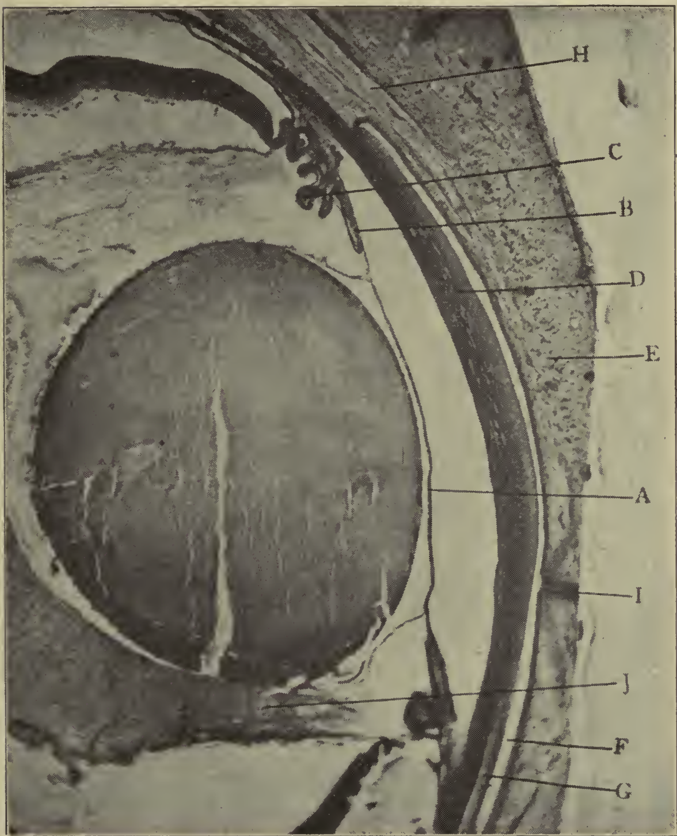

Fig. 22. Vertical section through eye of pig, 110 mm. long. Magnified 480 times.

fully developed, also the fibers. G, Fig. 21, shows the vitreous body and H shows the retina practically as is found in the adult eye.

A, Fig. 22, shows the pupilary membrane stretching across the pupilary space, and in it may be seen little white areas. These are the branches of the hyaloid artery which furnishes the nutrition to the lens during its development, and it will be remembered that this artery atrophies before birth and that the pupilary membrane disappears, ostensibly being absorbed. At B, Fig. 22, is shown the iris growing out from the ciliary bodies. C and D shows the cornea and in it is shown the lacuna (small lakes), which are minute openings between the layers of the lamina propria (proper layer), and E shows the lid with its developing structures. F, Fig. 22, shows the conjunctival sack and G shows the ocular conjunctiva and just back of it the anterior portion of Tenon's space. H, Fig. 22, shows the levator palpebra superioris (the lifter of the upper lid). I shows the lids held together by the cement substance and J shows the vitreous body (glass-like body).

CHAPTER II.

ANATOMY.

Having hurriedly described the development of the eye ball, we will now go over the adult eye, giving the gross and leaving the minute anatomy until we have advanced farther with the subject. The adult eye ball is 24.5 mm. across, 24 mm. from front to back, 23.5 from top to bottom, weighs a fraction less than one-quarter ounce and is composed of the segments of two spheres; the anterior portion, or the cornea, A, Fig. 23 (meaning hornlike), being the segment of a much smaller sphere than the posterior or scleral portion, the cornea comprising one-sixth of the outer surface, while the sclerotic (hard or tough), shown at B, makes up the other five-sixths. The cornea is transparent and thus forms the window through which the light is admitted to the eye ball and this transparency allows us to see the iris (rainbow), E, the structure lying directly behind the cornea. The iris is a circular structure pierced at the center by the opening known as the pupil. It contains two muscles, the one surrounding the pupil, which is a narrow band of circular fibers known as the sphincter pupillae muscle (meaning the binder muscle), K. This muscle closes the pupil, to protect the delicate tissues at the back of the eyeball from bright or intense light, then the dilator pupillae muscle, the fibers of which extend from the base of the iris to the sphincter pupillae. This muscle enlarges the pupil when more light is required to form a denser picture on the retina. The lens, F, lies just back of the pupil but can only be seen after it has lost its transparency. Continuing backward from the base of the iris, will be seen the ciliary body,

I, and between this structure and the sclerotic is found the ciliary muscle, H. In front of the ciliary muscle and at the base of the iris, is seen the pectinate ligament (comblike ligament), Q and J. This is made up of many small bundles of connective tissue, running from the periphery of the cornea to the base of the iris, across the angle formed by the junction of the cornea and the iris. This angle is known as the filtration angle, for the aqueous fluid, which fills the anterior and posterior chambers, leaves the eyeball, at this point. It passes into the spaces of fontana (fountain spaces), the spaces of fontana simply being the space between the bundles of fibers forming the pectinate ligament, and from these spaces the aqueous fluid, or nutrient lymph, as it is sometimes called, passes through the tissues to the canal of Schlemm, which is seen in Fig. 23 in the cornea just outside of the spaces of fontana. The canal of Schlemm is a circular channel within the corneal tissue, extending clear around the periphery of the cornea and the fluids pass from the canal of Schlemm to the anterior ciliary veins. Extending backward from the ciliary bodies and continuous with them, are the ciliary processes. These end near the ora serratta (saw tooth mouth), X, of the retina. Running from the ora serratta forward to the lens, imbedded in the outer layer of the hyaloid membrane and bound down firmly to the inner surface of the ciliary processes and bodies is the suspensory ligament or Zonule (belt) of Zinn, as Dr. Zinn first described it, G. The ligament proper is made up of very elastic fibers, which, as before stated, are imbedded in the outer layer of the hyaloid membrane. The hyaloid membrane surrounds the vitreous body and these fibers, the writer believes, to be elongated fibers of Mueller, which be-

came attached to the lens during foetal life when the fornix (arch) of the primary and secondary optic vesicles were in apposition (touching) to the equator of the lens and as the

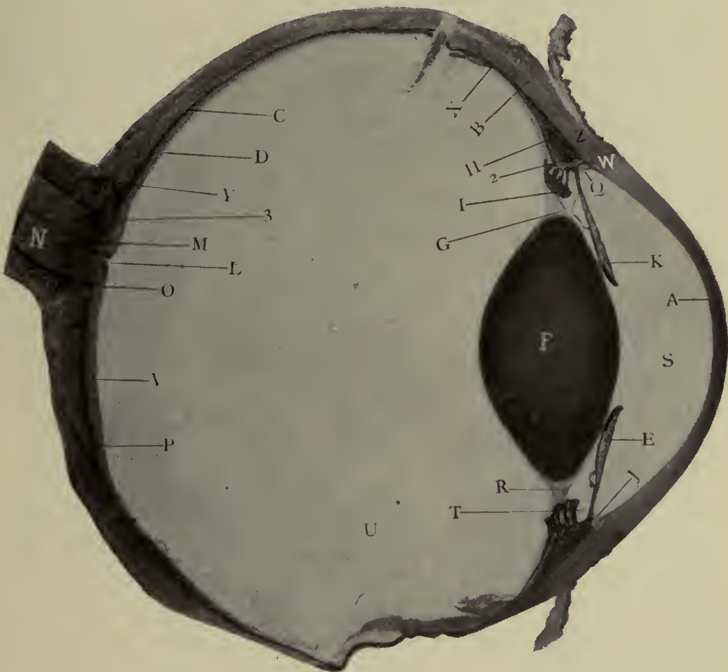

Fig. 23. Cross section of the Eye, showing its construction.

globe enlarged they elongated. See Figs. 7 to 20. This ligament leaves the ciliary bodies and passes across the space between them and the lens, a part of the fibers passing a little anterior of the equator and the rest a little posterior to the equator of the lens and are attached to the capsule

of the lens. The triangular space formed by this separation of the suspensory ligament fibers is known as the Canal of Petit, shown at R. The lens, F, is a transparent body and occupies the space just back of the iris and between the circle of inward projecting ciliary bodies. It is round, and flattened from before backward, its anterior and posterior surfaces being convex, the posterior surface having the shorter radius of curvature. It lies in a depression in the anterior surface of the vitreous body. This depression is known as the fossae Patellaris (dishlike depression) and is supported by this and the suspensory ligament. The lens is surrounded by a dense transparent membrane known as the capsule. The space in front of the ciliary bodies, suspensory ligament and lens, and back of the iris, is known as the posterior chamber, T, and the space in front of the iris and lens at the pupilary space and behind the cornea, is known as the anterior chamber, S.

The sclerotic coat (tough coat), B, continues backward from the cornea by continuity (continuation of tissue by blending one into another) of tissue over the posterior five-sixths of the eyeball to the optic nerve, where it divides, the inner portion forming the lamina cribrosa (sieve layer), M, whilst the outer portion passes into the sheath of the optic nerve Y. It is pierced by the ciliary arteries P; by nerves which enter the eyeball in a circle surrounding the nerve; by the vena vortacosa, four or five of which leave the eyeball just back of the equator; and by the anterior ciliary arteries and veins which enter the eyeball at the attachments of the extrinsic muscles, just back of the cornea. The region where the cornea ends and the sclerotic begins is known as the limbus (seam), W, and the angle or depression formed by the difference in the radius of curvature of the two spheres, represented in the formation of the eyeball in the corneal and scleral portion Z, is known as the sclero corneal sulsus (furrow). This angle makes the eyeball stronger and more firm at this point and it is just inside,

opposite this angle that the ciliary muscle, H, is attached anteriorly, whilst posteriorly the longitudinal fibers are attached to the outer surface of the choroid, in the region of the ciliary processes and bodies, as this muscle is interposed between the sclerotic and choroid in this region. The ciliary muscle, H, is made up of two sets of muscular fibers, the longitudinal running antero-posteriorly which are placed farthest out, next to the sclerotic, and the circular fibers which lie farthest inward, just outside of the ciliary bodies. These last named fibers take a circular course and form a band of circular fibers extending entirely around the ciliary ring.

Just inside of the ciliary muscle and sclerotic is found a very vascular pigmented layer, C, known as the choroid (meaning membrane). This is loosely attached to the sclerotic by the exchange of bundles of tissue called trabeculae and this space so formed is known as the supra choroidal space. The choroid is the middle tunic, or coat, of the three grand tunics of the eyeball. It is extremely vascular and it is analogous to the pia mater of the brain. The choroid, ciliary processes, ciliary bodies and the iris constitute what is known as the uveal coat (grape skin coat), and the three combined line all the scleral portion and compose the iris or curtain in front of the lens. Posteriorly the choroid is pierced by the optic nerve and this opening is known as the choroidal fissure (choroidal opening). As before stated, the posterior ciliary arteries and nerves pass through the sclerotic to reach the choroid. Here the short, posterior ciliary arteries, P, from twelve to twenty in number, divide, one branch running toward the optic nerve; the others run anteriorly and begin to subdivide as they run forward supplying the choroid, and some branch to the sclerotic. Two of the internal branches may be seen near the optic nerve in Fig. 23, the final destination of the anterior branches being the ciliary bodies, where they form capillary loops and turn backward as venous capillaries.

These capillaries keep joining with others and forming constantly larger veins, till finally there are great whorls formed in the region of the equator, where great numbers join to form the vena vortacosa which leave the eyeball just back of the equator to empty into the ophthalmic vein. Close inspection of this layer in Fig. 23 will reveal minute white spots all through its expanse and these white spots are cross sections of the arteries and their branches as well as the veins of the whorls from which the vena vortacosa are formed within the tissue. There are two long posterior ciliary arteries which enter the eyeball with the short set of arteries; one enters just inside, the other just outside of the optic nerve. These pass forward in the choroid without giving off any branches, until they reach the ciliary region. Here they each divide into branches which take a circular course and form a circle of anastomosis at the base of the iris and form what is known as the circulus major (the largest circle), 2, of the iris. The anterior ciliary arteries also join in this network, forming an anastomosis with them; then from this outer or larger circle branches pass into the iris and run toward the free margin or pupil, and when these reach the region of the sphincter pupillae muscle, another circle of anastomosis is formed and this is called the circulus minor (smallest circle) of the iris; from this smaller circle are given off capillaries, which form a circle of loops right at the free margin of the iris. These turn back as capillary loops, run one into another and become larger and larger and finally form veins known as the anterior ciliary veins and these veins also receive the aqueous humor from the canal of Schlemm, and therefore drain the anterior chamber. This was proven by injecting coloring matter into the anterior chamber, then after a few moments killing the animal and finding this colored matter in the anterior ciliary veins. The anterior ciliary veins leave the eye ball at the muscular

attachments and pass away from the eye ball in the muscles finally reaching the ophthalmic vein from them.

The ciliary nerves, about twenty in number, which arise from the ciliary ganglion (knot), enter the eyeball in a circle just outside of the optic nerve. They run forward in the supra choroidal space, giving off branches. Supplaying this structure, as well as the sclerotic, they run forward and form the ciliary plexus, which lies in the ciliary muscle. From this plexus branches run to the iris and cornea, supplying motor impulses to the sphincter pupillae muscle, dilator pupillae muscle, as well as trophic and sensory functions to the iris proper; the branches passing to the cornea are trophic and sensory only.

Just outside of the optic nerve, where it pierces the eyeball, is found a circle of anastomosis, giving a pretty free blood supply to the sheath at this point and sending branches into the substance of the nerve, to supply nutrition to the sustentacular, or binding tissue, which forms trabeculæ (beams) between the nerve bundles. This circle, O, is known as the circulus of Zinn, as he was the first to describe it.

Passing to the inner surface of the wall of the eyeball, we find the third of three grand tunics known as the retina (net), D. This lines the inner wall from the head of the optic nerve, also called the optic disc, or papillae, to the ora serratta. It is made up of seven layers of nervous tissue, two layers of connective tissue and one single layer of columnar pigmented cells. The nine innermost layers are held together by the sustentacular or binding tissue, which is known as the fibers of Muller. The outer or pigmented columnar layer is intimately attached to the choroid, while the other nine layers are loosely attached to this layer, yet firmly attached to the choroid at the ora serratta, while the arrangement of the nerve fiber layer and the passing of the axis cylinder processes through the choroidal fissure and

their continuation into the optic nerve bind the retina down firmly at this point. The retina is the nervous tunic and the most sensitive in the eyeball and is the one which makes possible the sense of sight. Its most sensitive area lies just outside of the optic nerve and is known as the macula lutea, V (the yellow spot), so named from the fact that if examined after death, it will be seen to have a yellowish hue. Then again the central spot within the macula is known as fovea centralis (or central pit). The retina thins down and leaves a cone-shaped pit, there being only two layers at this central spot. The retina receives its blood supply from the arteria centralis retina (central artery), 3. This enters the eyeball in the substance of the optic nerve, having become incorporated in the nerve during the folding of the optic stalk and vesicles during foetal life. See Figs. 10 and 11. When it passes through the choroidal fissure it divides, one branch passing upward, the other downward. These are known as the superior and inferior branches. Each subdivide, making four branches; one running upward and toward the nose, another upward and toward the temple, another downward and inward toward the nose, and another outward and downward toward the temple and from the direction taken they are named. The one running upward toward the nose is known as the superior nasal branch, whilst the one running downward toward the nose is known as the inferior nasal; the one running upward toward the temple is known as the superior temporal, the one running downward toward the temple is known as the inferior temporal branch. The farther subdivisions become so small and are so inconstant in their arrangement, that they have never been named. These vessels are imbedded in the retina, ramifying in the four innermost layers. They are readily seen with an ophthalmoscope from the fact that the retinal tissue surrounding them is transparent. These vessels keep dividing till they become capillaries and turn back as venous capillaries. These capil-

laries keep joining and rejoining until the vena centralis retina is formed and this passes out by the side of the arteria centralis retina. These veins are normally about one-third larger than the arteries and as they carry venous blood, which is loaded with waste products, they are of a darker red color when viewed with an ophthalmoscope.

As before stated the sclerotic coat posteriorly divides into three parts, the outer portion continuing into the sheath of the optic nerve, Y, the middle portion passes to the pial sheath, while the innermost portion breaks up into bundles and bridges across the space just back of the choroidal fissure, passing through the optic nerve and as these fibers come from all points and pass across in all directions, there is formed a sieve-like layer which is known as the lamina cribrosa (sieve layer). This reinforces the globe at this point, which otherwise would not stand the strain exerted by the normal tension within the eyeball. The optic nerve fibers pass through the meshes in this sieve layer and the optic nerve proper commences just back of this, where the insulation in the form of the myelin (marrow) sheaths begin. The opening through the lamina cribrosa, through which the arteria centralis retina and veins pass, is known as the porus opticus. At the head of the optic nerve, at the inner wall of the eyeball, there is found a shallow, funnel-shaped pit, L, known as the physiological cup (normal cup). This pit is formed owing to the fact that when the axis cylinder processes reach the choroidal fissure and turn backward over the edge of the choroid, they make a gradual symmetrical turn, instead of running out and making a sharp right angled turn, so the innermost fibers join at the center, after having bent to a certain extent, thus leaving this normal depression. This depression of course is filled by the vitreous body.

The space surrounded by the retina, ciliary processes, ciliary bodies, suspensory ligament and lens, is filled by the vitreous body, U. This is made up of shapeless cells, more

to be compared to an open meshed sponge than anything else, and fluid and the whole body is of the consistency of the white of an egg. It is surrounded by the hyaloid membrane, which lies on the inner limiting membrane of the retina. At the ora serratta, this hyaloid membrane divides. The outermost layer is firmly attached to the inner surface of the ciliary processes and bodies and passes from the ciliary bodies to the lens, and imbedded in it are the fibers of the suspensory ligament. The innermost layer continues over the front of the vitreous body and lines the fossae patillaris (dish-like depression), in which the lens rests. The vitreous body and its surrounding membrane are perfectly transparent. Running forward from the head of the optic nerve to the posterior of the lens, is a lymph space, known as the hyaloid canal, or the canal of Stilling; this was the channel through which the hyaloid artery passed to supply nutrition to the developing vitreous and lens, during foetal life. See Fig. 16. This artery atrophies before birth, and leaves this canal. The cornea, aqueous humor, lens and vitreous, form the refractive media of the eye, from the fact that they are transparent and are of different densities and different curvatures, so arranged that light entering a normal eye is brought to a focus at the retina.

The eyeball has numerous lymph spaces and channels. The space between the sclerotic and choroid is known as the supra choroidal space. The greater portion of the contents of the eyeball are fluids, which are practically the same as lymph found in other parts of the body; they are furnished by the osmosis (passing out), of the fluids of the blood through the walls of the capillaries in the ciliary bodies. A portion passes into the canal of Petit and back into the vitreous body, while the rest passes into the posterior chamber, part directly from the anterior portion of the ciliary bodies and part from the canal of Petit. The supra choroidal space is filled with fluids and is drained by the lymph spaces accompanying the vena vortacosa. In healthy eyes all these

fluids are constantly being supplied and rapidly passing out, so they do not become stagnant.

The orbits are four sided and pyramidal in form. The base is formed by the brim of the orbit, A, Fig. 24. The apex is at the sphenoidal fissure or opening, shown at B. The opening at the brim of the orbit, transversely, is one and one half inches, while vertically it is but one and one-fourth inches. Its depth, from the brim to the sphenoidal foramen, is one and three-fourths inches. The roof arches somewhat and the floor is slightly depressed, while the outer and inner walls are straight. The walls of the orbit are formed by seven bones. The roof is mainly formed by the orbital plate of the frontal bone, shown at C, and a very small portion at the posterior of the orbit by the lesser wing of the sphenoid, shown at D. The inner wall, from before backward, is formed by the nasal process of the superior maxillary, shown at E, lachrymal F, ethmoid H, orbital process of the superior maxillary G and the orbital portion of the sphenoid I. The floor is formed by the orbital plate of the superior maxillary J, orbital process of the plate K and a small portion of malar L. The outer wall is formed by the greater wing of the sphenoid M, and the orbital process of malar N.

The openings in the walls in the orbital cavity are as follows: On the interior wall, from before backward, the lachrymal canal, leading to the nasal cavity, through which the lachrymal duct passes; the anterior and posterior ethmoidal foramen (opening), through which the nasal branch of the ophthalmic nerve and artery leave the orbit; at the apex the sphenoidal fissure, through which the third, fourth, sixth and ophthalmic branches of the fifth nerve enter the orbit and the ophthalmic vein leaves it; above and to the inner side of the sphenoidal fissure is found the optic foramen O. It is through this opening that the second or optic nerve and the ophthalmic artery enter the orbit. At the lower, outer side, is found the spheno maxillary fissure P. It is through this

Fig. 24. The Human Skull.

opening that the upper branch of the superior maxillary or middle division of the fifth or trifacial nerve enters the orbit. It lies in a groove in the floor of the orbit at Q, and leaves the orbit with the infra orbital artery through the infra orbital foramen R.

Above the orbit, at its brim, is found a small opening, known as the supra orbital foramen, shown at S, through which the supra orbital nerve and artery leave the orbit. Sometimes this fails to fill in with bone at the brim and then only forms a notch, as shown at T. The inner walls are practically straight, from before backward, while the outer walls run obliquely backward and inward. Thus it will be seen that the axial poles of the two orbits diverge something like thirty degrees. The two eyeballs occupy the anterior central portion of the orbits. The rest of the orbit is filled with the orbital fat and the structures necessary for the performance of ocular functions and protection to the eyeball.

Covering the front, or base of the orbit and in front of the eyeball, are found the two lids, the upper and the lower, known as the palpebræ and shown at G and H, Fig. 25. The opening between the two lids, through which the eyeball is seen is known as the palpebral fissure and where the two lids join, at the outer and inner sides of the eyeball, is called the outer and inner canthus, as shown at A and B. Near the inner canthus, the two lids approach one another, then separate again slightly, before coming together, and this little circular portion of the palpebral fissure is known as the lakus (meaning small lake, and is so called because the tears flow into it before leaving the palpebral fissure). Lying within the lakus is a small, red body, formed of mucous tissue and of some few very fine hairs, also the remains of the schneiderian gland, which is found in those lower animals which have a third eyelid or nictitating membrane. This body is called the caruncle (small growth of flesh), shown at C, and just outside of the caruncle is found a fold of the conjunctiva (which membrane lines the lids and covers all the portion of the eyeball which is exposed when the lids are parted, except the corneal portion). This fold is the remains of the membrana nictatans and is called the plica semilunaris (half moon fold), and is shown at F. All along

the free margin of the lids, there is a row of hairs, which extend forward, with a slight turning upward at the outer ends on the upper lid and downward on the lower lid. These are the cilia (hairs) or eyelashes.

As before stated, when the lids approach, near the inner canthus, they arch away from each other, to form the lakus

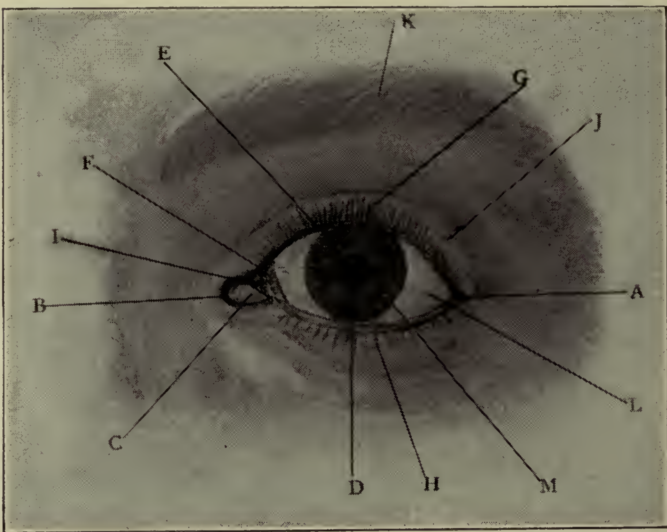

Fig. 25.

and on the free margin of the lids at this angle, is found a small, slightly raised point, known as the lachrymal papillae (tear pimples), shown at I, from the fact that in the center of each one is found a little opening, called the lachrymal puncta (minute opening), so named from the fact that the tears pass out of the palpebral fissure through these two openings. At the anterior central portion of the eyeball is seen a round, dark area, shown at D, with a central, smaller, round and darker area, shown at E. The outer, lighter portion, is the iris, and the smaller, darker portion is the opening

through its center, known as the pupil. These are seen through the transparent cornea, M, and all the opaque, or white portion of the eyeball, seen from in front, is the sclerotic, L, which is seen through the transparent conjunctiva. When the lids are separated, there is seen above the palpebral fissure, a fold of skin, J, which is caused by a bundle of fibers from the muscle which raises the upper lid passing outward and being attached to the skin, which draws the lower part of the skin, covering the lid, upward and al-

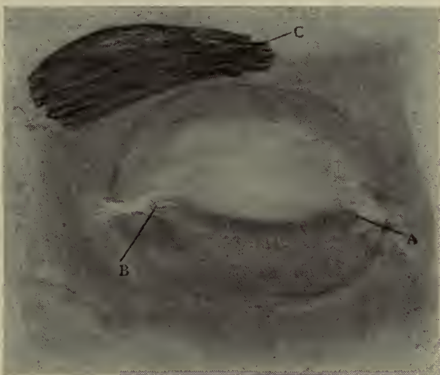

Fig. 26. Showing Tendo Oculi.

lowing the skin covering the upper part of the lid to drop down, forming the fold, and in this way nature has provided against this loose skin dropping over the edge of the lid and obscuring vision, when the lid is raised and the skin slackened.

Above the orbit, and covering a ridge, is a growth of hairs called the supra cilia (the hairs above) or eyebrows, K. This ridge is known as the supra ciliary ridge and is caused by a ridge of bone and a muscle underlying the skin. If the skin were dissected away, immediately beneath it would be found the superficial facia covering the deeper structure of the lids and stretching across the orbit. This is a thin, fibrous sheet, which is found immediately beneath the skin

and areolar tissue in all portions of the body. At the outer and inner sides of the palpebral fissure, running from the canthi to the orbital walls, is seen the external and internal angular or palpebral ligaments, also called the orbicular ligaments (shown at A and B, Fig. 26), and just above the orbit would be seen the corrugator supra ciliary muscle (supra ciliary wrinkler) shown at C. It arises from the frontal bone near the median line and along the supra ciliary ridge,

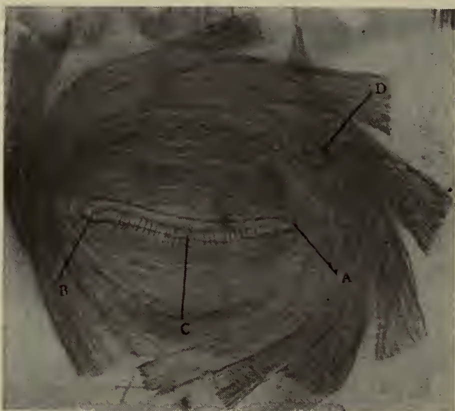

Fig. 27. Showing Orbicularis Muscle.

and is attached to the upper and outer fibers of the orbicularis muscle. It is the contraction of this muscle which causes the vertical wrinkles in the skin at the lower central portion of the forehead. Its nerve supply comes from the facial nerve, yet there seems to be a reflex action between this muscle and those of accommodation, for we see this corrugation or wrinkling most frequently in those who are hyperopic.

If we dissect away the superficial facia, immediately beneath it will be found the orbicularis palpebrarum muscle (circular muscle of the lids) shown at D, Fig. 27. It arises from the bony walls of the orbit at the brim. The bundles

of fibers pass inward and take a circular course and surround the palpebral fissure C, being continuous around the two canthi, A and B. This muscle is supplied by the facial nerve, and its action is to close the palpebral fissure and bring the free margins of the lids into apposition (touching), thus hiding the eyeball.

If the dissection is continued deeper, the deep facia would be exposed and in the region of the eye it is quite dense and fibrous and is called the ligament of Lockwood. It is shown

Fig. 28. Showing Ligament of Lockwood.

at A, Fig. 28. In it are embedded the tarsal (lid) cartilages, and above will be found the levator palpebrae superioris muscle (the lifter of the upper lid), shown at B. This muscle arises from the ligament of Zinn, which surrounds the optic foramen; it runs forward and upward and its tendon spreads out fan-shaped and is attached to the upper edge of the tarsal cartilage; a few fibers pass out and are attached to the skin. Its nerve supply is from the third, or motor oculi.

At the upper, inner side of the orbit, is seen the trochlea (pulley), shown at C, and passing through it and turning outward and downward, to be attached to the eyeball, is seen the superior oblique muscle D. It arises also from

the ligament of Zinn, passes forward, upward and inward through the orbit, then becomes tendonous and passes through the trochlea, then runs outward, downward and backward, and is attached to the eyeball underneath and outside of the superior rectus muscle, just back of the equator. This muscle receives its nerve supply from the fourth or patheticus nerve. At the upper, outer side of the orbit is seen the lachrymal gland (tear gland), shown

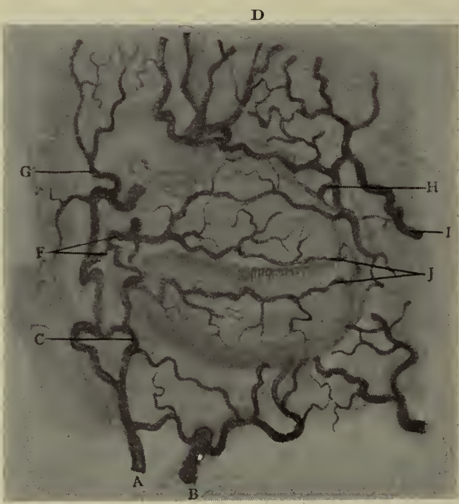

Fig. 29. Showing Arteries of the Lids.

at E. This is a compound racemose gland (resembling a bundle of grapes), and its ducts empty into the conjunctival sac, at the fornix conjunctiva (arch of the conjunctiva), at the upper, outer angle. This gland secretes the tears which are poured into the conjunctival sac, when the eye is irritated, to wash away any foreign substance which may be the cause of the irritation. This gland is especially supplied with sensory nerves from the branch of the ophthalmic nerve, which is named after the gland. At the outer

and inner canthi are again seen the angular ligaments F, and beneath the internal angular ligament, is found the tensor tarsi muscle, which is supplied by the facial nerve.

If the structures of the lids were dissected away, leaving only the arteries, their arrangement would be about as seen in Fig. 29. A is the angular artery, the terminal branch of the facial, and it is through this branch that collateral circulation to the brain is established, if the internal carotid is

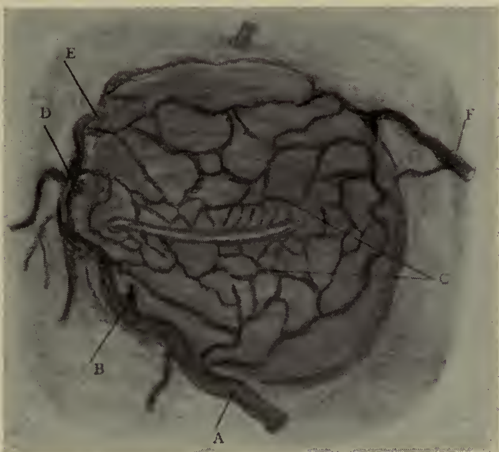

Fig. 30. Showing Veins of the Lids.

occluded, for it forms an anastomosis with the frontal artery G, this being the terminal branch of the ophthalmic artery. B is the infra orbital artery which comes to the surface from the orbit, through the infra orbital foramen. D is the supra orbital which comes from the orbit to the face through the supra orbital foramen. H is the lachrymal branch of the ophthalmic artery, after piercing the lid. I shows a branch of the anterior temporal artery as it comes to the region of the eye. This branch is of importance, from the fact that in acute inflammations of the orbit, or its contents, leeching

is resorted to on the temple, and it is the blood from this artery that is taken. E shows a branch from the transverse facial artery. Running across the lids, just above and below the opening, are seen two arterial trunks, F and J. They are divided into four arteries, the superior internal palpebral, the superior external palpebral, the inferior internal palpebral and the inferior external palpebral. It will be seen that the lids are well supplied with blood and that there is a free anastomosis of these vessels in and around the eyelids.

Fig. 31. Showing Nerves of the Lids,

Should all the structures of the lids be dissected away, leaving only the veins, Fig. 30 would be a fair representation. The names of these veins are the same as those of the arteries. A is the angular; B the infra orbital; C shows the veins draining the palpebral margins, which are supplied by the four palpebral arteries; D shows the frontal, which forms the anastomosis and is the branch through which all parts of the orbit are drained, if there is occlusion of the ophthalmic vein, near the cavernous sinus, at the back of the orbit. E points out the infra orbital and F the

anterior temporal. Thus it is seen that the drainage from the lids is abundant and this explains why it is that inflammatory conditions in this region are so easily controlled with hot or cold compresses.

If all other structures of the lids were dissected away, leaving the nerves only, Fig. 31 would give a fair idea of their arrangement. At A is seen the supra orbital nerve, after having emerged through the supra orbital foramen. At B, just outside of it, is seen the lachrymal nerve, after having pierced the lid, and at C are seen four branches coming from the facial nerve to supply the orbicularis palpebrarum. These are the only motor nerves shown in Fig. 31. The rest are all sensory nerves and are branches from the first and second divisions of the trifacial or fifth nerve. At D is seen the infra orbital nerve after emerging from the infra orbital foramen. It is the upper branch of the middle division of the trifacial nerve. At E are seen two branches emerging, the upper one passes above the trochlea and is known as the supra trochlear, while the lower passes below the trochlea and is called the infra trochlear nerve. The aggregation of small branches near the free margins of the upper and lower lids at F, is known as the plexus of Mises. It is thus seen that the lids are not wanting in sensory nerves.

If the lower portion of the nose were cut away and the deeper structures exposed between the palpebral fissure and the nose, we would find the lachrymal (tear) conducting apparatus, A, Fig. 32, which shows the canaliculi (minute canals) above and below the lakus (small lake), B. These empty into the lachrymal sac (tear sack) C, which becomes smaller as it extends downward toward the nasal cavity and is known as the lachrymal or nasal duct, D. This empties into the nasal cavity below the inferior turbinate, E, into the space known as the inferior meatus, F. At G is shown the middle turbinate and H shows the nasal cavity proper. At I will be seen the tendo oculi or palpebral ligament cut

short. The lachrymal sack occupies a triangular space behind this structure, and in front of the tensor tarsi or Horners' muscle, and when these two structures are made taut, as is the case when the eye is closed, this arrangement causes a pulling forward and outward of the anterior portion of the lachrymal sac by the palpebral ligament, while at the

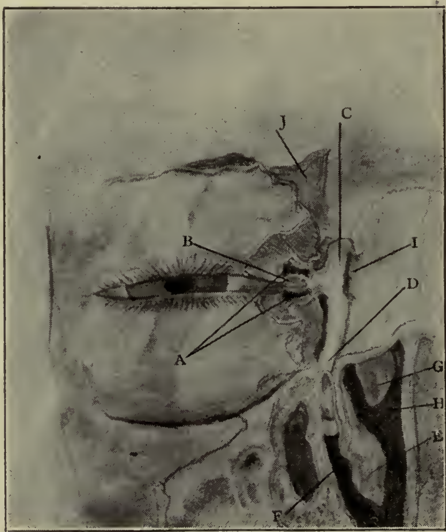

Fig. 32. Showing Canaliculi and Lachrymal Sac and canal emptying into the nasal canal.

same time the tensor tarsi muscle pulls the posterior portion outward and backward, thus distending the sac. Below the lachrymal sac there are valves in the lachrymal duct leading to the nasal cavity. These open downward and close the duct when there is suction from above, as is the case when the sac is distending, and the closing of the lids (which has distended the sac) has turned the lachrymal papilla, I, Fig. 25, so that their tips, where the lachrymal puncta are located, are pressed into the lakus, B, Fig. 32, and C, Fig. 25. As

the lachrymal duct is closed there is produced a suction at these openings so that any of the lachrymal fluid (tear fluid) which may be in the lakus is drawn into the canaliculi and onward into the lachrymal sac. When the eye is opened and the lachrymal sac collapses the valves in the lachrymal ducts open and the fluid is given free passage into the nose.

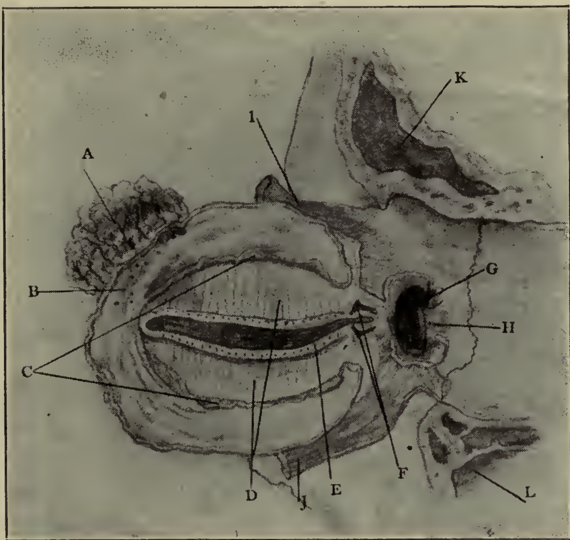

Fig. 33. Showing Conjunctival Surface of the Lids.

So it is seen that we have here a truly mechanical pumping apparatus to carry the tears from the eye. At J is seen the corrugator supracilia muscle.

Should we separate the lids from their attachments and leave only the attachments between them and the nose and swing them around forward, to clear the orbit, and look at the posterior or conjunctival surface of the lids, we would behold about the picture as seen in Fig. 33.

At A is seen the lachrymal gland and at B the openings through the conjunctiva where its ducts empty into the con-

junctival sac at the fornix. C shows the conjunctival tissue, dissected from the back of the lids, exposing the tarsal cartilages in which are imbedded the meibomian glands, shown at D, and their ducts opening onto the free margin of the lids, E. These glands secrete a sebaceous (oily) material which helps to lubricate the lids as they glide over the eyeball and also prevents the lids from sticking together when we sleep. Another function is that as the margins of the

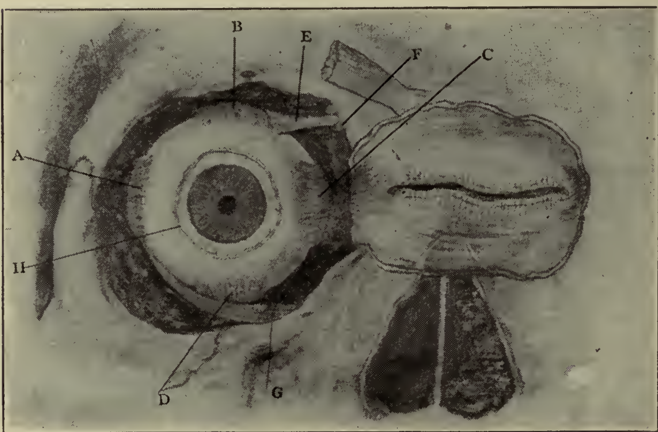

Fig. 34. Showing the Anterior Attachment to the Eye Ball of the Recti Muscles.

lids are kept oiled all the time, the tears do not flow over them so readily and as the two lids come into apposition at the outer angle first and then gradually close the palpebral fissure from without inward toward the nose, the lachrymal fluid flows inward toward the lakus instead of over the margin of the lid and on to the cheek, as it would do if it were not for this sebaceous material being so freely distributed along the free margin of the lid. This oily substance also mixes with the tears and helps to prevent friction between the eye ball and lids, as well as keeping

the cornea oiled so it does not dry so quickly as it otherwise would.

F shows the location of the canaliculi and G the lachrymal sac; H shows the tensor tarsi, or Horners' muscle, cut away; I shows the corrugator supracilli; J shows the levator labii superioris et aliqua nasi muscle (the lifter of the upper lip and the wing of the nose). This muscle arises just below the inner side of the orbit.

K shows the frontal sinus and L shows the maxillary sinus. These two sinuses sometimes become diseased and affect the eye on account of their nearness to it.

Should the lids be severed throughout their extent except at the inner side and swung out across the nose and all the tissue of the anterior part of the orbit dissected away, except the globe and recti muscles, as shown in Fig. 34, we could see the anterior portions and the attachments of the four straight recti muscles, A, B, C and D, the tendon E and pulley F, of the superior oblique and almost the whole of the inferior oblique muscle G as it arises from the floor of the orbit well forward and runs outward and slightly backward passing below the inferior rectus and is attached to the lower posterior quadrant of the eyeball. H shows the ocular conjunctiva, cut in a circle just outside of the cornea.

Should we make a horizontal cross section through the orbit and its contents, dissecting away all structures except the ligaments, fascias, etc., we would find the arrangement about as shown in Fig. 35. At A is shown the lid with the orbicularis palpebrarum muscle B, and the tarsal cartilage C, with the conjunctiva D, lining the conjunctival sac E, in which lies the plica semilunaris Q. At either side, in front, running from the lid to the brim of the orbital bones, is seen the orbito tarsal ligament or tendo oculi F, and just back of it, at the internal side, is found the tensor tarsi muscle or Horner's muscle H. Just next to the wall of the orbit and placed between the tendo oculi and the tensor tarsi muscle is found the lachrymal sac I. At either side of the globe, run-

ning forward from the internal recti muscle K and the external recti muscle L, is seen the check ligaments of these muscles G. These are bands of fascia from the muscle sheaths, which run forward and blend with the deep fascia or ligament of Lockwood, which stretches across the front or base of the orbit within the lids, above and below the palpebral fissure. These check ligaments prevent ex-

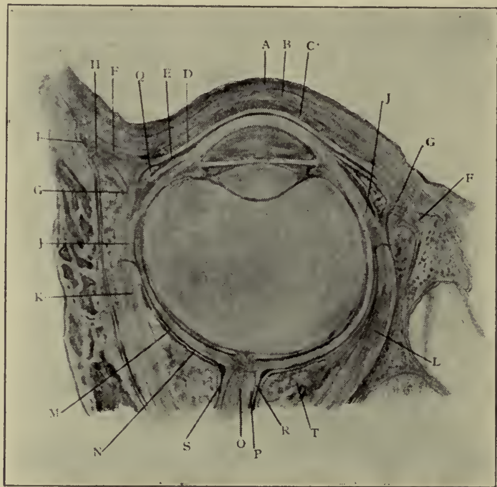

Fig. 35. Cross Section of Orbit and Contents.

treme action of the muscles, which otherwise might do harm to the optic nerve, by rotating the eyeball too greatly. Just outside of the posterior portion of the eyeball is seen the space of Tenon N, which is a lymph space, and outside of it Tenon's sheath or capsule. Tenon's space is crossed by loose bundles of connective tissue, running from the sclera to Tenon's capsule and vice versa. These are known as trabeculae (fibrous bands). These are very loose and of sufficient length to allow free movements of the eyeball in the socket formed by Tenon's capsule. When the recti

muscles come near to the eyeball, the sheaths of the muscles blend with the capsule of Tenon, as shown at J, and it must be borne in mind that this connection greatly modifies the action of the recti muscles. Posteriorly is seen the optic nerve O, surrounded by the intra vaginal space P, and surrounding this space is found the sheath of the optic nerve, which is continuous with the sclerotic, and outside of the

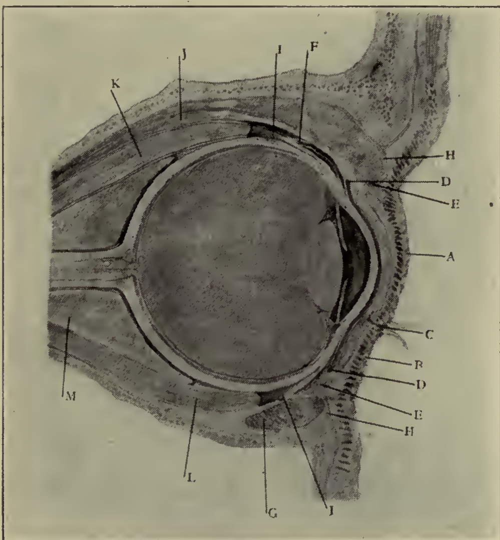

Fig. 36. Vertical Cross Section of Orbit.

optic nerve sheath is found the supra vaginal space S, which is continuous with the space of Tenon. This is surrounded by Tenon's capsule, filling in the spaces between the eyeball and the posterior or apex of the orbit, and between the muscles and other structures, is found the orbital fat T. This acts as a cushion for the eyeball as well as filling the spaces between the structures of the orbit.

Fig. 36 shows a vertical cross section of the orbit; above and in front is seen the upper lid A and below in front is

the lower lid B, the slit between them, the palpebral fissure C. Back of the lids, and in front of the cornea, is the conjunctival sac and above and below is seen the fornices (folds) D, where the conjunctiva leaves the lid (palpebral conjunctiva) and folds on itself, forming the fornix and then covering the anterior of the eyeball (ocular conjunctiva), ceasing at the edge of the cornea. At E, Fig. 36, is found the check ligaments of the levator palpebral su-

Fig. 37. Showing the Muscles of the Orbit.

perioris J, and the inferior rectus L, and at F is seen a band of tissue running from the upper side of the superior rectus muscle K to the lower side of the levator palpebrae. This band of tissue forms the check ligament of the superior rectus muscle. At H is seen the deep fascia or ligament of Lockwood. At G is seen the inferior oblique muscle with its sheath and the intimate relation of its sheath with the

sheath of the inferior rectus I, and the capsule of Tenon. This is of importance from the fact of the modification of the action of the inferior oblique which it causes. At M is seen the orbital fat.

Should the roof of the orbit be cut away and all the structures of the orbit dissected away except the muscles,

Fig. 38. Showing Vessels of Orbit.

eyeball and the lachrymal gland, we would see about such a picture as shown by Fig. 37. The levator palpebrae superioris A, which occupies the uppermost portion of the orbit, is cut and thrown forward and exposes the superior rectus B, which lies just below it. At the inner side and above is shown the superior oblique C, running through the trochlea or pulley D, then its tendon E running obliquely outward and backward to its attachment to the globe F, be-

neath the superior rectus. Just beneath and outside of the superior oblique, is seen the internal rectus muscle K. At A is seen the external rectus muscle and between it and the eyeball is seen the attachment of the inferior oblique muscle H. At the floor of the orbit, just back of the eyeball, is shown a small portion of the inferior rectus muscle J. All these muscles, except the inferior oblique, arise from the ligament of Zinn, which surrounds the optic foramen at the apex of the orbit. In the upper anterior portion of the orbit is shown the lachrymal gland I.

Should the roof of the orbit be cut away and all the structures of the orbit dissected away, except the arteries, veins, eyeball and lachrymal gland, we would see a picture about as portrayed in Fig. 38. Coming from the internal carotid artery, comes off the ophthalmic artery A, which enters the orbit through the optic foramen with the optic nerve. It first gives off the lachrymal branch D, which takes a course outward and upward to the position of the gland I, which it supplies, and after giving off branches to the gland, it pierces the lid and supplies the superficial structures of the lid, at the upper outer side of the orbit. The next branches given off are the several short posterior and long posterior ciliary arteries B, which run forward and pass into the eyeball in a circle around the optic nerve and run forward in the choroid. Shortly after these branches are given off, the arteria centralis retina is given off. This artery passes into the optic nerve ten or twelve millimeters back of the eyeball and passes through the choroidal fissure and gives the blood supply to the retina. There are also muscular branches given off which pass into the muscles and run forward in them to their attachments to the eyeball. These arteries pierce the sclerotic and enter the eyeball and are then known as the anterior ciliary arteries C. Then the supra orbital branch is given off, which runs upward and forward and passes out of the orbit through the supra orbital foramen and supplies the structures just above the

orbit. The posterior H, and anterior E, ethmoid branches, are then given off. These pass through the posterior and anterior ethmoidal foramen, which are found in the upper posterior portion of the internal bony wall of the orbit. They first pass into the cranial cavity, then run downward through the cribriform plate of the ethmoid bone to supply the internal and anterior portion of the nose. Anteriorly the ophthalmic artery gives off the frontal artery. These two then pierce the lids and one or the other forms an anastomosis with the angular artery, which is the terminal branch of the facial artery. This is of importance, from the fact that if the internal carotid artery or the posterior portion of the ophthalmic artery should be occluded (stopped up), collateral circulation would be established by this route. Accompanying all the larger arteries are found the veins, which carry the return flow of blood, and these veins are known by the same name as the artery which they accompany. However, there are no veins leaving the eyeball with the posterior ciliary arteries, but the drainage from the choroid is by the Vena Vorticosæ, J. These leave the eyeball just back of the equator and there are usually about five in number. All these veins join to form the ophthalmic vein L, which passes backward through the sphenoidal fissure and empties into the cavernous sinus.

As shown at B, Fig. 38, the ophthalmic artery gives off several small branches which enter the eyeball in a circle around the optic nerve. There are some twelve to twenty of these, which are known as the short posterior ciliary arteries and two known as the long posterior ciliary arteries. Should we enucleate the eyeball and dissect away all the tissues down to the choroid and leave only the long and short ciliary arteries, Fig. 39 would give us a fair representation of their distribution. The short posterior ciliary arteries, A, from twelve to twenty in number, enter the eyeball by piercing the sclerotic in a circle just outside of the

optic nerve. Immediately after entering the sclerotic, they divide, the main portion running forward (See P, Fig. 23) and enter the choroid, breaking up into smaller vessels and lay in three strata or layers, the layer of large blood vessels, the layer of small blood vessels, which is immediately

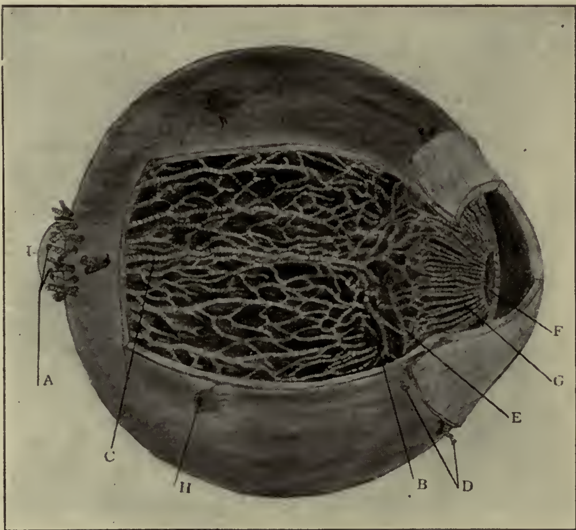

Fig. 39. Showing Ciliary Arteries.

beneath it, and the chorio capillaris or capillary layer, which is the innermost layer and is just beneath the retina. The larger vessels run forward in the choroid and ciliary processes to the ciliary bodies, which are just inside of the ciliary muscles B, where they end in capillary loops and turn back as venous capillaries, while the branches given off in their course form the layer of smaller blood vessels and these again break up into the chorio capillaris. The branches that turn toward the optic nerve, just after the short posterior ciliary arteries enter the sclerotic (See Fig.

23) form a circle of anastomosis around the optic nerve, known as circulus of Zinn, as shown at O, Fig. 23. This circle furnishes a copious blood supply to the head of the optic nerve as well as furnishing a path for the establishment of collateral circulation, when there is trouble with the branches which supply the nerve sheath with which they also connect or anastomose.

There are two long posterior ciliary arteries, C, which enter the eyeball a little farther out than the short posterior ciliary arteries, one to the outer side of the nerve and one to the inner side. These run forward clear to the ciliary region, before they branch, and then when they do branch they join with, or anastomose with the anterior ciliary arteries, which enter the eyeball at the attachments of the recti muscles D, and these then form what is known as the circulus major (larger) of the Iris E, Fig. 39, and 2, Fig. 23. From this circle is given off the vessels for the iris, which run radially in toward the pupil G, and when these come near to the free margin of the iris another circle of anastomosis is formed, which is known as the circulus minor F, Fig. 39, and E, Fig. 23. Inside of this, toward the pupil, are given off arterial capillaries which turn back as veins, which are drained by the anterior ciliary veins, which leave the eyeball at the muscular attachments D. At H is seen the vena vorticosa (whirlpool) and at I is seen the optic nerve.

Should the eyeball be enucleated and the sclerotic and the tissues dissected off, leaving only the veins of the posterior four-fifths of the eyeball, we would find practically the arrangement as seen in Fig. 40. The smaller veins pass back from the ciliary bodies at A from underneath the ciliary muscle F. These veins constantly join or anastomose with others and form four or five whirls, B, finally join to form the four or five vena vorticosae (whirlpool veins) C, which leave the eyeball just back of the equator and empty into the ophthalmic vein. See J. Fig. 38.

As previously mentioned the ophthalmic artery gives off one branch, which enters the optic nerve at its under surface and about ten to twelve millimeters back of the eyeball, which is known as the arteria centralis retina (central

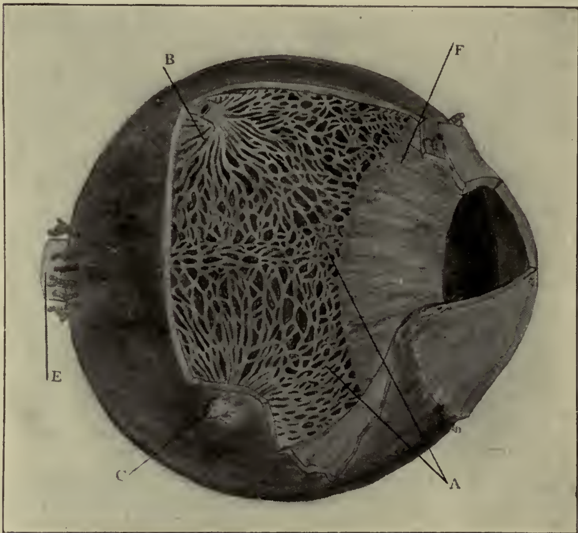

Fig. 40. Veins of the Eyeball.

artery of the retina), from the fact that it enters the eye ball at the optic disc and spreads out to supply the retina (See 3, Fig. 23), and if we should take an eyeball and make a coronal cut down through it at the equator, then hold it up and look at the inner surface of the globe, we would see the picture as portrayed in Fig. 41. At the disc A are seen the arteries emerging from the head of optic nerve or disc and the veins leaving. The artery first breaks up into two branches, one running upward, the other downward. These are known as the upper, B, and lower, C, branches. These in turn each divide into two branches. Each of these four branches runs obliquely outward from the disc, the upper one

running inward toward the nose is called the superior nasal, D, and the one running upward and outward and toward the temple is called the superior temporal, E, while the one below, running inward toward the nose is known as the inferior nasal, F, and the one running downward and

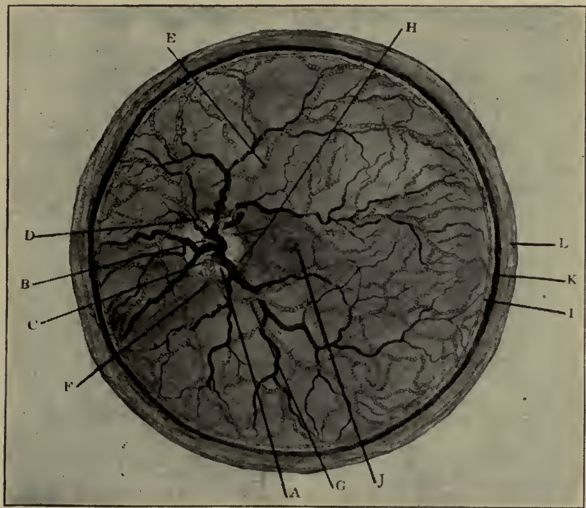

Fig. 41. Arteries of the Retina.

outward toward the temple is called the inferior temporal, G. The farther divisions of these arteries are unnamed. However, there are usually one or two small arteries, which run from the disc toward the maculae, which when present are called the macular arteries, H. These arteries and veins lie in the retina, I, and the arteria centralis retina is what is known as a terminal artery, or in other words, it forms no anastomosis with any other set of arteries, consequently when it breaks up into capillaries, these turn back as veins. These keep joining together and get larger and larger until there are large veins formed, which are named the same as the arteries which they accompany. As there is

usually a vein accompanying each artery, these join at the disc and form the vena centralis retina which leaves the eyeball within the optic nerve and lies within it for some ten or twelve millimeters. It then leaves the nerve and empties into the ophthalmic vein (See Fig. 23). The fact of the arteria centralis retina being a terminal artery in the retina having no collateral loops or anastomosis, as is the case in almost all other portions of the body, makes this of especial clinical significance, for if it becomes occluded, the nourishment is cut off from the retina and sight is lost and the retina atrophies in an exceedingly short period.

Just to the temporal side of the disc is seen the macula (spot) and at its center the fovea centralis (central spot) J. It is so named from the fact that it is the thinnest spot in the whole retina and turns yellow after death. It is not seen as a yellow spot during life, with an ophthalmoscope, as some inexperienced ones think, but as a dark area devoid of visible blood vessels and the yellow appearance which we see in examining the posterior inner surface of the eyeball after death is a post mortem (after death) change. K shows the choroid and L the scleral coat of the eyeball.

Should we cut away the roof of the orbit and dissect away all the tissues except the nerves, eyeball, recti muscles, levator superioris and the lachrymal gland, Fig. 42 would be a fair representation of what we would observe. At A we see the sixth cranial or abduceus nerve, which innervates the external rectus muscle J, and at B is seen the third cranial nerve or the motor oculi, which furnishes nerve impulse to the levator palpebrae superioris K, the superior rectus L, the internal rectus M, the inferior rectus N, and the inferior oblique O, besides giving branches to the ciliary or lenticular ganglion Q. At C is shown the fourth cranial or patheticus (cry) nerve which supplies the superior oblique muscle I. At D is shown the fifth cranial, trigeminus or trifacial nerve, and E the gasserian ganglion on the fifth nerve, and at F the upper or ophthalmic branch of the

fifth nerve which supplies sensation to the orbit, eyeball and its structures as well as the lids, and G the superior maxillary nerve or the middle branch of the trifacial or fifth nerve, and H the lower branch or the inferior maxillary nerve. However, we are only particularly interested in the first, upper or ophthalmic branch, and just slightly interested in the second, or superior maxillary branch, for the ophthalmic nerve gives off first the nasal branch, R, which

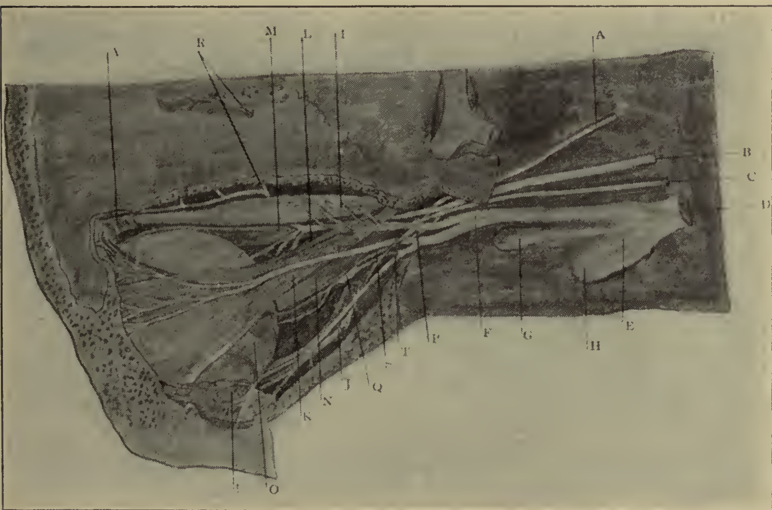

Fig. 42. The Nerves of the Orbit from Above.

runs upward and inward through the orbit, giving a branch or root S to the lenticular ganglion Q, then passes out of the orbit to re-enter the cranial cavity through the ethmoidal foramen, then it leaves the cranial cavity again through the cribiform plate of the ethmoid bone and supplies sensation to the anterior portion and the tip of the nose, and it is this branch which accounts for the reflexes between the nose and the eye. Then the ophthalmic gives off the lachrymal branch, T, which runs upward and outward to the

lachrymal gland, U, and after supplying the gland it pierces the lid and supplies sensation to the upper outer part of the lid (See B, Fig. 31). The ophthalmic then gives one or two branches or roots to the lenticular ganglion direct and continues upward and forward. The main portion of the nerve leaves the orbit through the supra orbital foramen and is known as the supraorbital nerve (See A, Fig. 31). However, just before leaving the orbit it gives off a branch which divides, and one branch pierces the lid above the

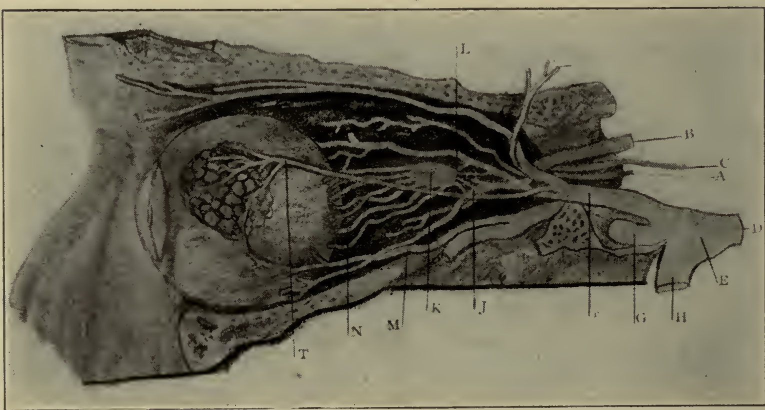

Fig. 43. The Nerves of the Orbit from the side.

pulley or troclea, V, of the superior oblique muscle. This branch is known as the supra trochlear (See E, Fig. 31); the other one pierces the lid just below the trochlea and is known as the infra trochlear branch (See E, Fig. 31).

Should we make a vertical section of the walls of the orbit and dissect away the tissues, leaving only the eyeball, nerves and lachrymal gland, we would have the appearance as shown in Fig. 43. At A is shown the sixth or abduceus nerve, which is cut and thrown up at I, and at B is seen the third cranial or motor oculi nerve, and at J its branches or roots to the lenticular ganglion, K, and at D is shown the

fifth cranial nerve, and at E the gasserian ganglion. At F is shown the first division, which is known as the ophthalmic nerve, and at L is shown its branches to the lenticular ganglion. At G is shown the second division or superior maxillary nerve, but in the study of the eye we are only interested in two of its branches; first the one shown at M, known as the orbital nerve, which goes to the lower outer side of the eyeball, forming an anastomosis with the lachrymal nerve, T, and the terminal branch runs forward and passes out onto the face through the infra orbital foramen (See D, Fig. 31) and supplies the sensation to the lower lid and region just below the eye. This branch is known as the infra orbital nerve.

The lenticular ganglion, K, is of vast importance to the eyeball. It is a small pinkish body about the size of a pinhead and is situated some seven to ten millimeters back of the eyeball. On the outer side of the optic nerve, between it and the ophthalmic artery, it receives filaments, or roots, J, from the motor oculi nerve, which are motor from the nasal nerve, L, as well as from the ophthalmic nerves which are sensory. It also receives filaments or roots from the sympathetic nervous system, which comes from the carotid plexus. Thus it is seen, there are motor, sensory and sympathetic filaments received by it. Then from this ganglion is given off the posterior ciliary nerves, N. These are mixed nerves and carry motor, sensory and sympathetic fibers. These nerves, from twelve to twenty in number, enter the eyeball posteriorly with the posterior ciliary arteries (See A, Fig. 39, and A, Fig. 44). These pierce the sclerotic just outside of the optic nerve in a circle and pass forward mostly in the supra choroidal space, and if we should enucleate an eyeball and dissect away the sclerotic and all other structures except the nerves, we would have a picture as shown in Fig. 44. The posterior ciliary nerves, B, run forward in the supra choroidal space and give numerous branches to the choroid, C, in their course. They then break up into small

branches, D, and these form a plexus in the ciliary muscle, E, and from this plexus is given off branches to the ciliary muscle which are motor to the ciliary bodies which are sympathetic and sensory, then other branches to the iris, F, which are sensory, motor and sympathetic, the motor for the spincter pupillae (See K, Fig. 23), sympathetic, for the dilator pupillae muscle. Other branches go from the ciliary

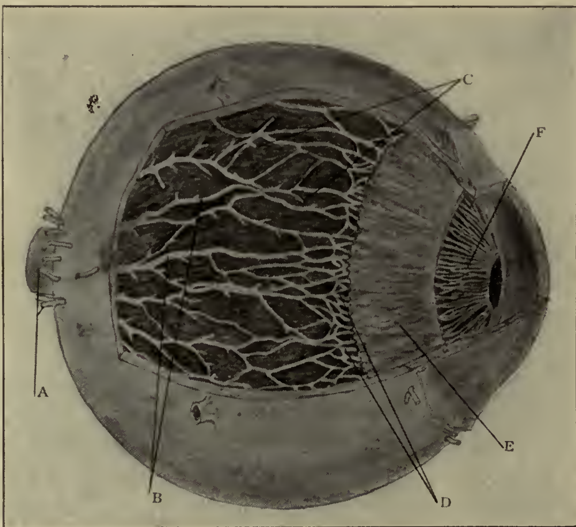

Fig. 44. Showing Ciliary Nerves.

plexus to the cornea which are entirely sensory. Thus it will be seen that the nerve supply to the eye is abundant and of all three varieties, motor, sensory and sympathetic.

Having covered the gross anatomy of the eye pretty thoroughly, we will now pass to the more minute anatomy or Histology and in so doing it is well for the reader to be familiar with the gross anatomy, in order to be familiar with the relation of parts.

CHAPTER III.

HISTOLOGY.

We will first take up the lids or palpebrae (from palpare—to stroke). These are two crescentic folds, which grow from above down and from below upward and cover the front of the eyeball. See Figs. 9 to 17, showing their development from the margin of the orbit. Their function is purely the protection of the eyeball and they contain many glands, all of which secrete substances which play their parts in the physiological functions of the lids. The lids also contain two semilunar plates with their convex border turned away from the palpebral slit. These are very dense, fibrous plates, known as the tarsal cartillages U, Fig. 45. However, they have nothing in common with cartillage, except their density, they being made up wholly of white fibrous tissue. However, they were named by the ancient anatomists prior to the time of our ability, by chemical analysis, to determine accurately the constituents of all tissues and bodies.

The outer or anterior surface is covered with epithelium while the inner or posterior surface is covered with mucous membrane, the epithelium changing its nature at the free margin of the lid.

Fig. 45 shows a vertical cross section of the upper lid. At A is shown the epithelium; at B is shown the hair follicles of the small white hairs, which are scattered over the anterior surface of the lids. At C is shown the sweat glands; at D the subepithelial tissue, or areolar tissue, which differs somewhat from that found in other parts of the body, from the fact that fat is not readily deposited in it, as is the case elsewhere in the body. Lying immediately below the areolar tissue is found the orbicularis palpebrarum muscle. The cross sections of the bundles are seen at E (also see Fig. 27)

and at F are shown the hair follicles of the cilia or lashes. At G are seen the modified sweat glands of Moll and at H are shown the sebaceous glands connected with the lash or cilia in the lids. These glands are known as Zeisse's glands. At I is seen the muscle of Riolanis. This is the involuntary muscle for closing the eye; it also re-enforces the orbicu-

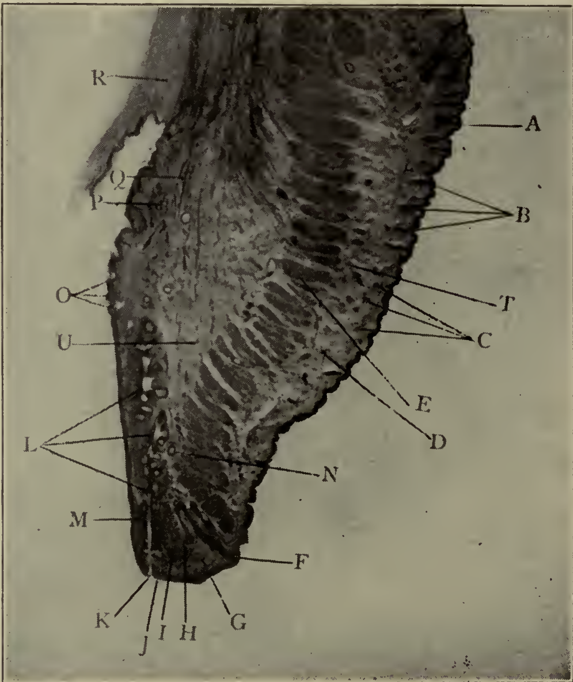

Fig. 45. Vertical Cross Section of the Upper Eyelid.

lars and brings the margins of the lids into close and firm apposition. J points to the region where the epithelium changes its nature to that of a mucous membrane, such as lines all cavities or internal openings which communicate with the external world, and in this case is known as the conjunctiva. At K is shown one of the ducts of a Meibomian Gland, and L shows the secreting portion of the

gland, which is imbedded in the tarsal cartillage. M shows the palpebral conjunctiva, and at N is seen a cross-section of one of the superior palpebral arteries (see G and J, Fig. 29). There is a free anastomosis between these arteries and those of the inner or conjunctival surface formed by numerous arteries piercing the tarsal cartillage. At O are seen the post tarsal papillae, which are folds, and the depressions be-

Fig. 46. Eyelid Showing Portion of a Hair Follicle.

tween them are called Henly's glands. At P are shown the glands of Waldeyer. At Q is shown the involuntary muscle of Mueller, and it is this muscular bundle which opens the eye involuntarily. At R are seen Kraus' glands, just above the fornix (arch) of the conjunctiva. S shows the fibers of the levator palpebrae superioris (see B, Fig. 28), and at T are shown the fibers from this muscle, which pass outward

between the fibers of the orbicularis palpebrarum, and are attached to the skin as shown at A in Fig. 52.

This fasciculus is a wise provision of nature, for when the lid is raised it keeps the skin taut between its attachment and the free margin of the lid, and draws it up with the lid, while the skin above drops down over it, making a fold

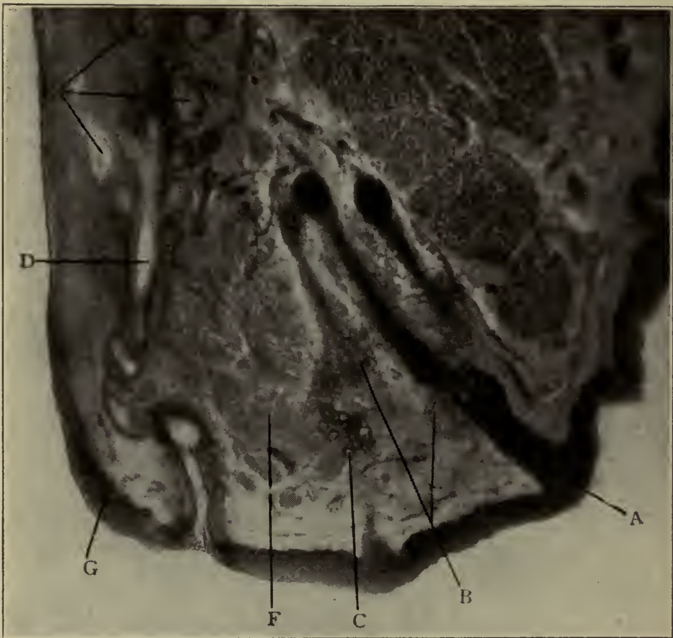

Fig. 47. Showing Zeisse's Glands, Modified Sweat Glands of Moll and Meibomian Glands.

in the skin at about the middle of the lid, and in this way takes care of the loose skin when the lid is raised, otherwise it would drop down over the edge of the lid and interfere with vision.

Fig. 46 shows the innermost portion of a hair follicle; G the papillae in the follicle, from which the hair grows and receives its nourishment mainly, and H the cup in the end of the hair shaft.

Fig. 47 also shows a hair follicle. B, Figs. 46 and 47, shows the sebaceous gland, known as Zeisses glands. In this location, these glands are compound sacular glands, the sacks filled with secreting cells, which secrete an oily material called sebum, which is poured into the hair follicle and travels along the lashes and keeps them oiled, so they are always soft and pliable. C, Fig. 46 and 47, shows the modified sweat glands of Moll, which are tubular glands, lined with secreting cells, which in other parts of the body lie doubled up in knots in the areolar tissue with straight tubes running to the surface. These modified sweat glands lie in the muscle of Riolanis, just back of the lashes. The modification of these glands on the margin of the lids is due to the fact that instead of opening onto the surface as sweat glands do elsewhere on the body, these empty into the hair follicle and this watery secretion becomes mixed with the sebum from Zeisse's glands and thereby renders it more viscid or watery. This serves the purpose of keeping the lashes constantly covered with this thin, viscid, oily substance, which facilitates their capacity for catching dust, thereby increasing the usefulness of the lashes in protecting the cornea against dust. F, Fig. 46 and 47, shows the muscle of Riolanis, which is a small muscular bundle, which surrounds the palpebral fissure and arises from the tendo oculi (see A and B, Fig. 26), however it is really a part of the orbicularis palpebrarum and is the involuntary muscle to close the eye when the cornea becomes dry. When acting in conjunction with the orbicularis in closing the eye, it causes a folding of the free margin of the lid and reinforces the orbicularis and brings the lid margins more closely together. D, Fig. 46 and 47, shows a duct of one of the meibomian glands and at E, Fig. 46 and 47, are the gland cells, which secrete the sebaceous material which is poured out on the free margin of the lid. The meibomian glands are modified sebaceous glands, being tubular with many blind pouches or sacks connecting, filled with secreting cells. There are from twenty to thirty of these glands in each lid. They are imbedded in the conjunctival surface of the tarsal cartillage and

are readily seen in the human lid (when inverted) as white lines, and their openings are readily seen on the free margin of the lid. See Figs. 33 and 34. This secretion renders four important services to the eye: First, this

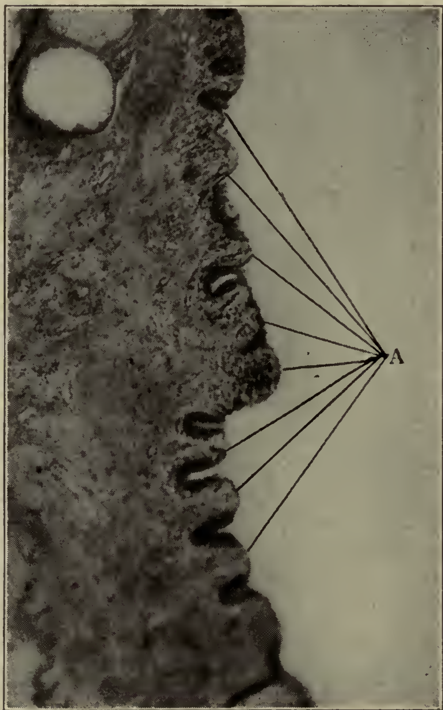

Fig. 48. Showing the Tarsal Papillæ.

oily substance prevents the lids from sticking together when we sleep; second, it keeps the margins of the lids oiled and prevents the tears from flowing over their edges, when the eyelids are being closed, for it will be remembered that the lids come into apposition at the outer canthus first, then the slit is gradually closed from without inward and any tears which have accumulated in the palpebral fissure flow along in

front of the closing edges; thus they are directed into the lakus (see C, Fig. 25); third, it keeps the cornea oiled, which prevents the cornea from dessication or drying so readily; fourth, its mixing with the tears and keeping the conjunctival sac so freely lubricated, prevents friction of the structures as they glide over each other in the opening and closing of the eye lids.

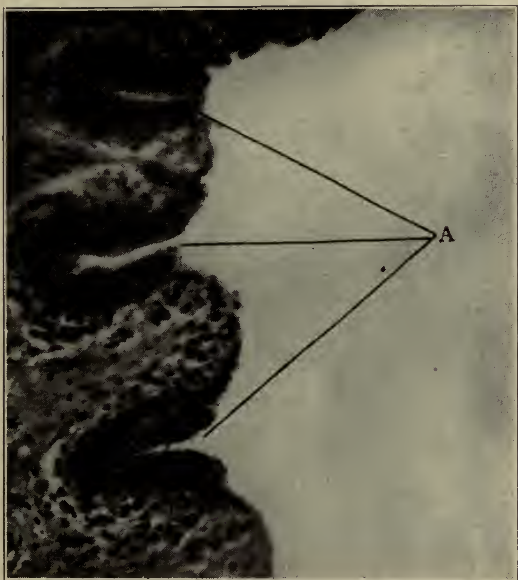

Fig. 49. Showing Henle's Glands.

A, Fig. 48, shows the post tarsal papillae, which in reality are only folds or Rouga of the conjunctiva which have the appearance of being small elevations when seen in cross section and where the mucous surfaces are brought into close proximity, as is the case in the furrows or depressions, the cells change their nature, and we find these furrows lined with columnar epithelial cells as shown at A in Fig. 49, and they are called Henle's glands. These glands, or folds,

become more marked as age advances. These surfaces contain many goblet cells and secrete more or less mucus.

At A, Fig. 50, are seen the glands of Waldeyer. These glands are in the nature of sweat glands and they with Kraus' glands (A, Fig. 51) secrete the tears under ordinary circumstances. At B, Fig. 51, are shown cross sections of the lachrymal gland, which is a compound tubulo racemose gland resembling serous or fluid secreting glands in other

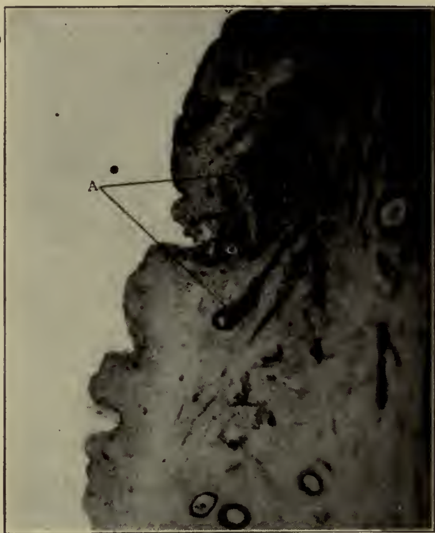

Fig. 50.

parts of the body. This is a rather larger gland than any we have seen in the lid before. It is located in the upper lid, at the upper outer side of the orbit (see E, Fig. 28); it is almond-shaped and the size of a small almond kernel. The secretions reach the conjunctival sac by some ten or twelve ducts (C, Fig. 51), which empty into the fornix (arch) of the conjunctiva. D, Fig. 51. The lachrymal gland, only pours forth its secretions when the eye is irritated, and this washes or floods the conjunctival sac quite freely,

as when the eye is irritated by a foreign body or when we cry, and the secretion of tears is so copious, that our lachrymal apparatus cannot carry away all the fluids, and we find the tears flowing over the lower lid onto the cheek at such times.

The conjunctiva (joined together) is the mucous membrane which lines the conjunctival sac (the joined sac), which is really two crescentic culdesacs, one between each

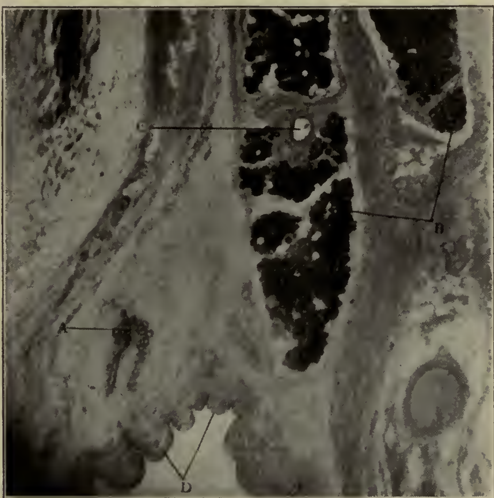

Fig. 51.

eyelid and the eyeball, and they are really separated by the palpebral fissure, when the lids are open. However, it is a complete oval sac when the lids are closed. This mucous membrane commences at the free margin of the lid, at B, Fig. 52, by the transformation of the epithelium into mucous epithelium, the arrangement of the cells is the same as in the epithelium in other parts of the body, the outermost cells being squamous (scaly), the middle cells being irregularly round or polyhedral (many sided) cells, while the innermost are columnar (long) cells. These lie

on a loose membrane which is well supplied with blood vessels, and the tissue being loose and transparent, it gives a free flow of Lymph. That part of the conjunctiva lining the posterior surface of the lids is known as the palpebral conjunctiva (C, Fig. 52). When it reaches well back under the lids, it folds on itself and becomes adherent to the sclerotic (H,

Fig 52.

Fig. 52). This fold is called the fornix conjunctiva (D, Fig. 52). The portion of the conjunctiva which covers the eyeball (E, Fig. 52) is called the ocular or bulbar conjunctiva. The ocular conjunctiva is transparent and through it we can see the sclera, which is opaque and white. It is freely movable over the sclerotic (K, Fig. 52) and by manipulation we can see the blood vessels of the conjunctiva (H, Fig. 52) change their position, while the blood vessels

of the sclera, which are deeper set (J, Fig. 52), remain stationary. When the conjunctiva reaches the outer margin of the cornea (G, Fig. 52) the basement tissue ends, but the epithelium continues over the front of the cornea (F, Fig. 52) and forms the anterior or stratified epithelial layer of the cornea, and is called the conjunctival portion of the

Fig. 53.

cornea. The blood vessels of the conjunctiva end at the corneal margin in a circle of capillary loops (I, Fig. 52, and F, Fig. 54), very superficially placed.

The cornea (horn-like) A, Fig. 23, and M, Fig. 25, forms about the anterior sixth of the eyeball. It is a highly transparent structure, allowing the light from the external world to enter the eyeball, and is the first of the refractive

media through which this light passes on its way to the retina. It is made up of five layers, as shown in cross section in Fig. 53; A, the anterior stratified epithelial layer; B, Bowman's membrane, or the anterior homogeneous membrane; C, the lamina propria (proper layer); D, Decimet's membrane or the posterior homogeneous layer, and E, the endothelial layer; the latter lining the cornea on its surface bounding the anterior chamber. See S, Fig. 23.

The anterior stratified epithelium, as before stated, is continuous with the epithelial layer of the conjunctiva. As its name implies, its cells differ at different depths. The outermost, F, is made of squamous (scaly) cells, G is formed by hexagonal (many-sided) cells, and the innermost layer, H, is formed by Columnar (long, square) epithelial cells and this is the layer where all new cells are formed by the division and growth of these columnar cells, and as new cells are formed the older ones are pushed outward toward the surface and become hexagonal, and as this process continues, the cells are pushed farther and farther out. They lose their nuclei and become mere flat scales and finally lose their adhesive qualities and are disquamated (thrown off) and wash away with the tears. These cells are held together both from the cement substance lying between them and by the little projections from the surface of the cells themselves. When these projections are found on a cell, they are called prickle cells, and this is the nature of these cells in the lower or inner layers.

Passing from without inward, the next layer, B, is Bowman's membrane, or the anterior homogeneous lamina.

As the name, homogeneous lamina, implies, this layer when seen with the microscope reveals no structural frame work, but appears as a solid gelatinous layer. However, if this tissue be macerated (soaked) in an alkaline solution and the cement substance dissolved out, it will be found to be formed of connective tissue bundles. This layer ends at the periphery of the cornea. The next layer, C, is the

Lamina Propria (proper layer) or substance of the cornea. It is formed of some sixty strata of connective tissue bundles. These cannot be stripped off in layers, but are made out by the microscope from the fact that the connective tissue bundles run in different directions; that is, for instance, in one strata all the bundles run vertically across the cornea, the next layer may run horizontally, while the

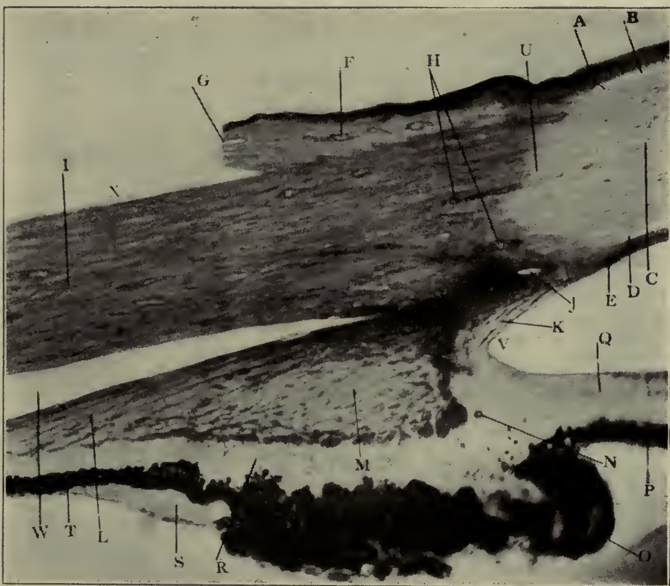

Fig. 54. Ciliary region, magnified 1,000 times.

third strata may have its bundles laying at 45° or 135°. However, there is such a free exchange of bundles from one layer to another, in which they become lost, that the whole sixty are practically as one; so that this arrangement forms a very firm, unyielding structure. At the sclero-corneal juncture or limbus, U, Fig. 54, the lamina propria continues backward, forming the sclerotic by continuity of tissue, the difference being simply that the nature of the

tissue is changed at the limbus, for in the cornea it has no blood vessels, while the sclera is fairly well supplied with blood vessels. In the cornea the tissue is quite dense and transparent, and in the sclerotic it is more loosely arranged and is opaque. In the cornea it is highly supplied with sensory nerves, while in the sclerotic it has only a moderate nerve supply, and, farther, if we should examine the cornea chemically, we would find it contained chondron (found in cartilage), while the sclerotic would show no chondron, but in its place we would find gelatin. It will then be seen that while one blends into the other, yet the two tissues are very much different.

The cornea is said to fit into the sclera as a watch glass fits into the bezel of a watch. This impression is given from the fact that the corneal tissue passes farther backward at its center, while the sclera runs forward farther at its outer and inner surfaces. When we view this with the microscope in stained sections, it appears as shown at U, Fig. 54. This is from the fact that the cornea being more dense than the sclerotic, it retains less of the stain in its preparation, so that we can make out the limits of the two tissues fairly well in this way.

Lying within the lamina propria is a network of openings or lymph channels, the lacunae, I, Fig. 53 (small lakes) and the minute canals (caniliculae) which run out in all directions from the lacunae and join the caniliculae from surrounding lacunae. Lying in these lacunae, I, Fig. 53, yet not entirely filling them, are found the fixed or corneal corpuscles. These cells in turn have very minute protoplasmic processes which run through the caniliculae and join or anastomose with the processes from the cells in the neighboring lacunae. These processes do not entirely fill the caniliculae in which they lie; thus it will be seen that we have a network of lymph channels through which the blood plasma, or nutrient lymph can have free passage to all parts of the cornea to supply it with nutrition. This

lymph is given off from the capillary loops, forming a circle around the margin of the cornea, which will be described later.

Passing inward, the next layer is Decimet's Membrane, or the internal homogenous lamina, D, Fig. 53. This is a very thin, highly transparent layer and has a tendency to curl up when stripped off of the cornea. When viewed with the microscope, it is impossible to make out any ground work, it seeming to be wholly made up of a hornlike membrane, but as with Bowman's membrane, if treated properly, to remove the gelatinous substance which forms the matrix or joins the component tissues together, it will be found to be formed of connective tissue. Many functions have been ascribed to this membrane, but the chief one is its great resistance to disease, such as corneal ulcers, etc. Some writers claim this membrane breaks up into connective tissue bundles, bridges across the filtration angle and forms the pectinate (comb) ligament, K, Fig. 54.

This is composed of hundreds of connective tissue bundles which run from the periphery of the cornea to the base of the iris, K, Fig. 54, and A, Fig. 53. This angle formed by the iris and cornea, V, Fig. 54, is known as the filtration angle from the fact that the aqueous fluid passes out of the anterior chamber between the bundles of tissue, forming the pectinate ligament, to the spaces of Fontana (fountain spaces), which comprises the openings in the pectinate ligament. The posterior, or fifth layer, is known as the endothelial layer, E, Fig. 53. This is formed of a single layer of cubical (square) endothelial cells, which are placed like paving blocks and are similar to cells which are found in other parts of the body, lining closed cavities, or cavities which have no opening communicating with the external world. These cells have the faculty to withstand the dissolving qualities of the aqueous fluid, or nutrient lymph, which fills the anterior chamber.

Some anatomists divide the cornea into three portions; the conjunctival portion, consisting of the anterior stratified epithelium, and Bowman's Membrane; the scleral portion, consisting of the lamina propria; and the choroidal portion, consisting of Decimet's Membrane and the endothelial layer. This is from the fact that these layers are supposed to be derived from these structures.

The sclerotic (tough) coat, I, Fig. 54, forms the posterior five-sixths of the outer coat of the eyeball, except a small opening at the posterior pole, where the optic nerve pierces it. This opening is known as the choroidal fissure. See Figs. 23, 56 and 57. The sclerotic, as before stated, is continuous with the cornea by continuity of tissue. Just outside of the sclerotic is the space of Tenon, X, Fig. 54, and N, Fig. 35. This is a space between the capsule of Tenon and the sclerotic. The capsule of Tenon forms a fibrous socket for the eyeball, and this space of Tenon is a lymph space and is crossed by many connective tissue bundles passing from the capsule to the sclerotic. These are known as Trabeculae. Internal to the sclerotic, between it and the choroid, is another lymph space known as the suprachoroidal space, W, Fig. 54. This is also crossed by an abundance of trabeculae passing from the sclerotic to the choroidal coat. In fact, the trabeculae are so numerous that it is almost impossible to separate the two structures. The sclerotic, as its name implies, is very tough and opaque. The innermost portion contains quite a little pigment. It has four layers, from without inward; they are the endothelial layer lining the space of Tenon, which is a single layer of pavement cells. Next comes the lamina propria (proper layer); the next layer is called the lamina fusca (Brown layer). The lamina propria and the lamina fusca are not sharply defined by any line of demarcation, but, as before stated, the innermost strata contains some pigment. It is therefore brown in color, the pigment not being sufficient to cause it to appear

black. This pigment is deposited in branched cells. The innermost, or fourth layer, is the internal endothelial layer, lining the supra choroidal space, and is of the usual pavement variety. The lamina propria and lamina fusca are formed of tough fibrous tissue, the strands of which run

Fig. 55. Magnified 2,500 times.

in all directions with a general anterior posterior arrangement. Lying in the substance of the sclerotic are found lacunae, the same as in the cornea which contains the fixed or scleral corpuscles, analogous to the corneal corpuscles. In fact, the sclerotic is very similar to the cornea in the arrangement of the connective tissue, except that it is not nearly so compact.

The sclera, as before stated, is well supplied with blood vessels. These run forward and end in capillary loops at the limbus and form a complete circle extending clear around the periphery of the cornea. They, with the circle of capillaries formed by the conjunctival vessels, F, Fig. 54, and I, Fig. 52, near the outer surface, give off the nutrient lymph which flows through the lacunae (small lakes) and caniliculi (minute canals) and permeates the cornea. This lymph furnishes the nutrition for the cornea. To give the reader an idea of what is meant by capillary loops, we have taken a microphotograph of an injected section from the sole of the foot. Fig. 55, A. This is the Rete Mukosum (capillary layer, or malpighian layer), of the skin, showing the fine capillaries running up and forming loops and passing back as venous capillaries. B shows some elevations, which form little ridges, which can be seen on the ball of the thumb so readily. C shows the branch of an artery, which breaks up into these small capillaries.

At J, Fig. 54, is seen the canal of Schlemm. This is a canal lying near the inner surface of the sclerotic, just at the limbus. It is circular in course, running clear around the margin of the cornea. It may be single, or may be composed of several small canals. They branch from and return to the main opening, so that it forms one continuous sinus, it is lined with endothelial cells, and is drained by the anterior ciliary veins. The aqueous humor passes from the spaces of fontana to the canal of Schlemm and eventually is carried back into the circulation by the anterior ciliary veins.

As before stated the sclerotic forms the posterior five-sixths of the outer coat of the eyeball. To it are attached the six recti (straight) muscles. See Figs. 35, 36 and 37. It is pierced by the anterior ciliary arteries and veins at these points of attachment. (See D, Fig. 39.) These pass through about eight to ten millimeters back of the limbus; then just back of the equator it is pierced

by the vena vorticosa (whorl veins) four to six in number. (See H, Fig. 39, and B. and C., Fig. 40) Then posteriorly it is pierced by the ciliary arteries and nerves, there being twelve to twenty of each. These pass through just outside of the optic nerve A, Fig. 39, and at A, Fig. 56, is seen one of these vessels passing through this structure. When the sclerotic reaches the optic nerve, it divides into

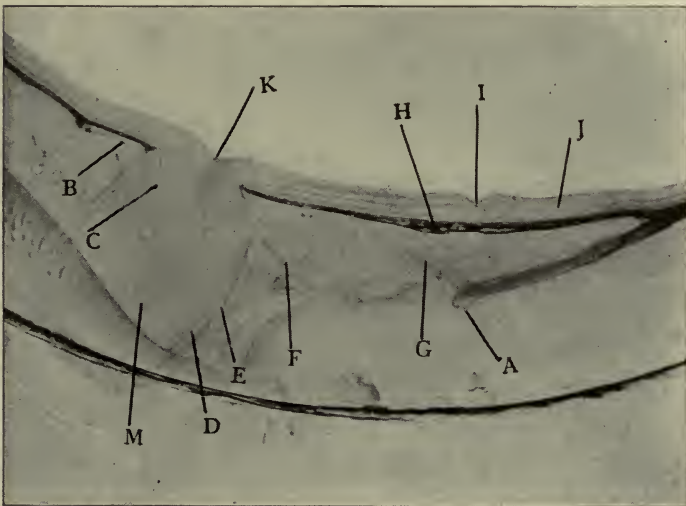

Fig. 56.

three portions. The innermost, B, Fig. 56 and 57, breaks up into individual bundles. These pass across the choroidal fissure and form the lamina cribrosa (sieve layer), C, Figs. 56 and 57. These bundles pass across in all directions and reinforce the eyeball at this otherwise weak point, leaving meshes or openings through which the optic nerve fibers pass out of the eyeball. It is also pierced by the arteria centralis retinæ (central artery of the retina) L, Fig. 57. The opening through the lamina cribrosa, through which the arteria centralis retinæ and vein pass, is known as the porus opticus.

The middle portion passes to and blends with the pia mater of the optic nerve D, Figs. 56 and 57. The outer portion passes into the sheath of the optic nerve, F, Fig. 56 and 57. At E is shown the intervaginal space of the optic nerve, which is continuous with the sub-dural space of the brain at the optic foramen and contains cerebro spinal fluid.

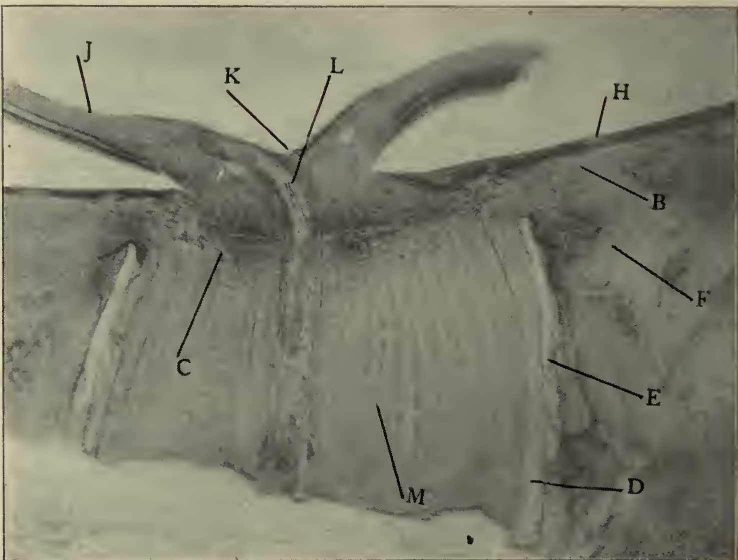

Fig. 57.

H, Figs. 56 and 57, shows the choroid, and J, Figs. 56 and 57, shows the retina detached from the choroid. K shows the physiological cup; M shows the optic nerve, and in Fig. 57 the nerve bundles are extremely well shown with the myelin sheaths surrounding them. These sheaths end normally just behind the lamina cribrosa, C.

The choroid is continuous from the optic nerve to the free margin of the iris, or to the pupillary opening. It lies inside of the schlerotic and is the second grand tunic or coat of the eye. From the ora serratta of the retina (saw tooth

mouth of the retina) to the choroidal fissure it lies in touch with the sclerotic, only being separated from it by the supra choroidal space and intimately attached to the sclerotic by the interchange of trabeculae passing across the supra choroidal space from one to the other. It is a pigmented and highly vascular tissue, as its name implies, and supplies the greater part of the nutrition and secretions of the eyeball.

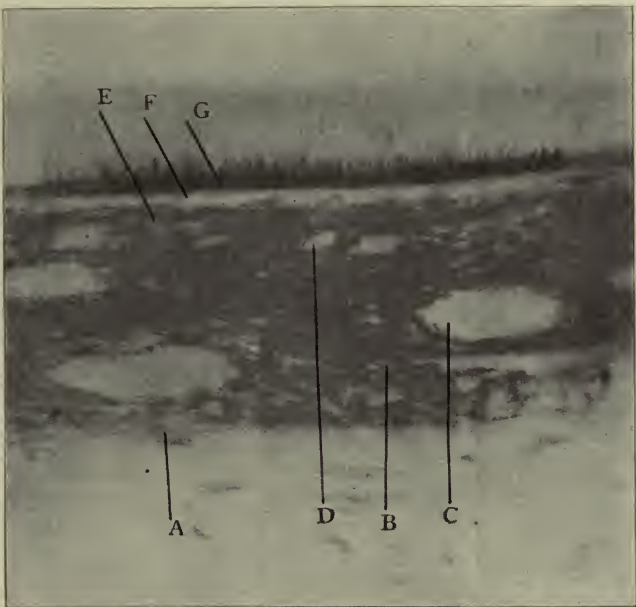

Fig. 58. Showing Section of Choroid.

It is composed of five layers of fibrous tissue with branched pigment cells in the meshes between the connective tissue fibers. First from without inward we have the endothelial layer lining the supra choroidal space, A, Fig. 58. Below that is the lamina supra choroidea (upper layer of the choroid), B, Fig. 58, also called the lamina fusca of the choroid, on account of its pigmentation and brown color.

The next layer is the layer of large blood vessels, C, Fig. 58. The next layer is known as the layer of small blood vessels, D, Fig. 58. The layer of large and small blood vessels

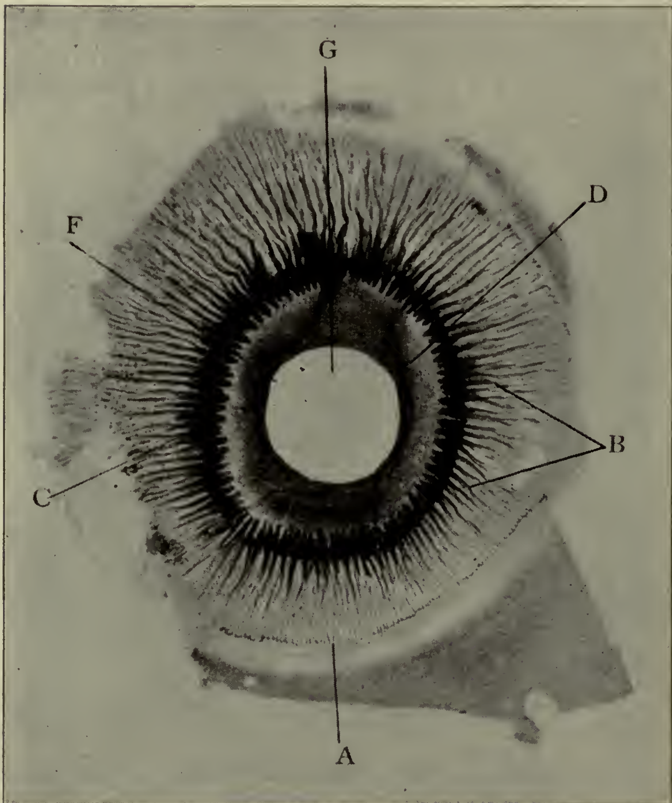

Fig. 59. Showing Ora Seratta, Ciliary Processes and Bodies and the Iris from Posterior Aspect.

are composed of the posterior ciliary arteries as they pass forward in the structure, giving off branches all along their course; also the veins which go to form the vena vorticosa lie in these two layers. The next layer is called the chorio

capillario (capillary layer of the choroid), E, Fig. 58. These capillaries are separated from the retina by the bacillary layer (basement layer), also called Brucks' Membrane or lamina vitrea, F, Fig. 58. The capillary layer of the choroid furnishes much of the

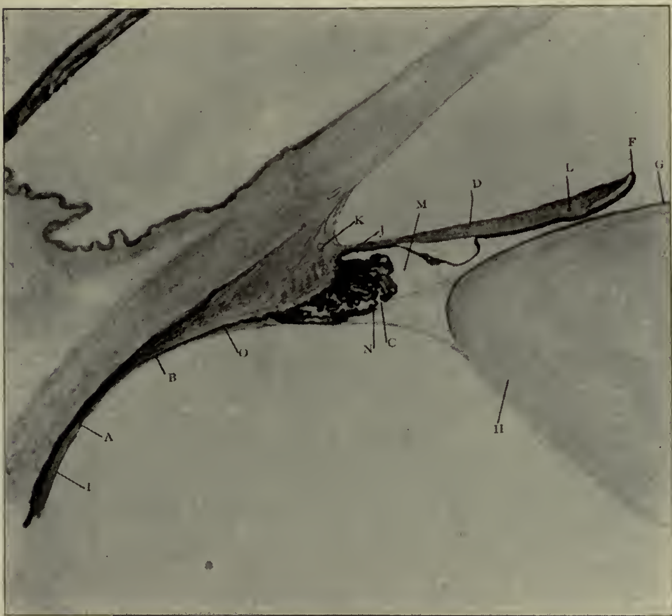

Fig. 60. Showing Same as Fig. 59 in Cross Section.

nutrition to the outer layers of the retina, it reaching them by osmosis (passing through) Brucks' Membrane. This layer is free from pigment and is rich in cement substance, so much so that it is a homogeneous membrane or layer.

The choroid is highly pigmented to prevent the light penetrating the wall of the eyeball, thus making an absolutely dark chamber of it. The choroid is extremely susceptible to disease on account of its extreme vascularity.

As before stated the choroid is continuous from the head of the optic nerve forward to the free margin of the iris. However, it is divided into the choroid ciliary process, ciliary bodies and iris. The choroid, I, Fig. 60, extends from the optic nerve to the ora serratta or anterior margin of the retina, A, Figs. 59 and 60. It then becomes somewhat ridged on its inner surface, B, Figs. 59 and 60. These ridges have an anterior posterior direction, and these ridges, about seventy in number, are known as the ciliary processes.

Fig. 61. The Capillaries of the Ciliary Processes.

These end in blunt endings which project into the cavity of the eyeball towards the lens, H, Fig. 60, and are known as the ciliary bodies, C, Figs, 59 and 60. From the outer angle of the bases of the ciliary bodies, J, Fig. 60, the choroid or uvea leaves the outer wall of the eyeball and takes a transverse direction. This transverse portion is called the iris (rainbow), D, Figs. 59 and 60. At the center of the (Doll so called from the diminutive image of oneself as seen in the pupillary area when looking into anyone's eye), transverse portion there is an opening known as the pupil,

G, Figs. 59 and 60. The free margin of the iris, F, Figs. 59 and 60, lies free and rests on the anterior surface of the lens, H, Fig. 60. The short, posterior ciliary arteries run forward through the choroid in the layer of large blood vessels, C, Fig. 58, and B, Fig. 39, being bunched in straight vessels in

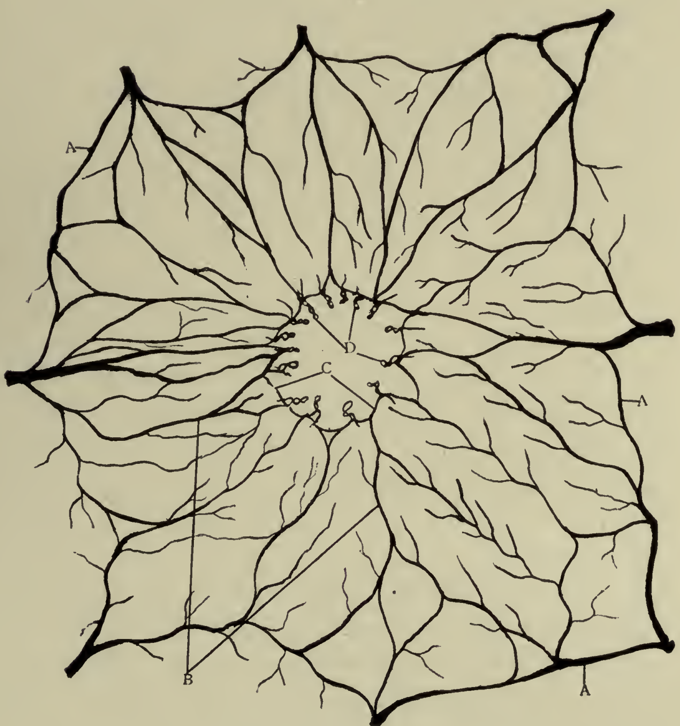

Fig. 62. The Blood Vessels of the Iris.

the ciliary processes and end in capillary tufts, Fig. 61, in the ciliary bodies, turning back as venous capillaries, A, Fig. 40. From the capillaries are given out the fluids of the blood which passes into the canal of Petit, N, Fig. 60,

and the posterior chamber, M, Fig. 60. This fluid is known as the aqueous humor.

The two long posterior ciliary arteries run forward in the choroid in the layer of large blood vessels, C, Fig. 58, and C, Fig. 39. They join the anterior ciliary arteries, D, Fig. 39, and form one arterial trunk, which lies right at the base of the iris, A, Fig. 62, K, Fig. 60, and E, Fig. 39. This arterial trunk formed by the anastomosis (joining) of the long posterior and anterior ciliary arteries, is known as the circulus major (larger circle) of the iris, A, Fig. 62. From the circulus major is given off branches which run radially inward toward the free margin of the iris, B, Fig. 62, These radially coursing arteries in the iris may be likened to the spokes in a wheel. When they come near to the free margin of the iris, they anastomose (join) and form another circle known as the circulus minor (smaller circle) of the iris, C, Fig. 62. From the circulus minor is given off capillaries which run inward toward the free margin of the iris. They double back as venous capillaries, D, Fig. 62. The drainage from the iris is by the anterior ciliary veins which leave the eyeball at the attachments of the extrinsic muscles, while the drainage from ciliary bodies and the rest of the uveal tract is drained by the vena vortacosa (vortex veins). See Fig. 40.

Anterior to the ora serratta the outermost or pigment layer of the retina continues forward in two layers of columnar epithelial pigmented cells and lines the inner wall of the eyeball over the pars ciliaris, retina, ciliary processes, and bodies, O, Fig. 60, also continuing over the posterior surface of the iris, clear to the free margin at F, Fig. 60. This is known as the retinal portion of these structures and the amount of pigment contained in this layer over the posterior of the iris largely determines the color of the eye, for if

there is no pigment in this layer, or the stroma of the iris, we would have the pink or albino eye. If there is a small amount of pigment in the retinal portion, then we would have a light blue eye; a little more pigment and it will produce the dark blue eye, and so on as more pigment is deposited, the eye is gray, brown or black. However, in the brown and black eyes there is much pigmentation of the stroma of the iris.

Fig. 63 shows a cross section of an iris in which the retinal portion, A, is well pigmented, while the stroma, B, has but a small amount of pigment. This would have a tendency to produce a light grayish color when the iris is viewed from the front. Fig. 64 shows a cross section of an iris, which is highly pigmented, both in the retinal layer, A, as well as the stroma, B. This would produce a dark brown or black iris if viewed from the front.

The iris is a very delicate structure formed of a very thin network of connective tissue, with a large amount of cells filling in the spaces between the connective tissue fibers. In dark eyes these cells become more or less pigmented, C, Fig. 64. The iris contains two muscles, the Sphincter (binder) Pupillae, A, Fig. 65, and the Dilator (enlarger) Pupillae, B. It has four layers from within outward; they are the pigment, or retinal layer, F, muscular, B, the stroma proper in which lie the blood vessels, E, and the endothelial or corneal layer, D. The front of the iris has deep depressions or crypts; these run radially, or from the base toward the free margin. These depressions, or crypts, lie between the blood vessels, see Fig. 62, and in medium or light colored eyes this causes the stellate (star like) or radially spoke-like appearance of the anterior surface of the iris as seen in those eyes. Fig. 66 represents a quadrant of the front surface of an iris; A, the pigment layer at the free margin; B, the circulus minor and capillaries; C, the circu-

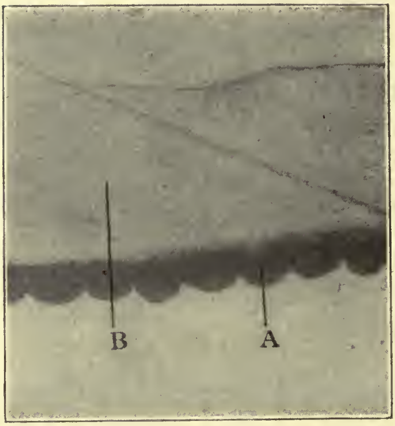

Fig. 63. Cross section from iris of a light colored eye.

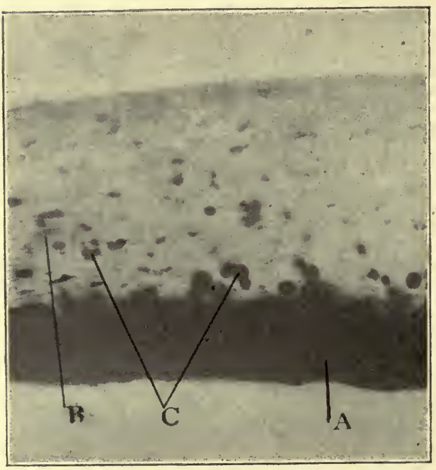

Fig. 64. A cross section of Iris from dark Eye.

lus major; D, a trabeculae or ridge in which runs a blood vessel; E, a depression or crypt; and F, the pectinate ligament. The spoke or stellate appearance is caused by the vessels being so near the surface that the reflection is greater over them than from the spaces between them. However, in very dark eyes, the pigment is so densely deposited

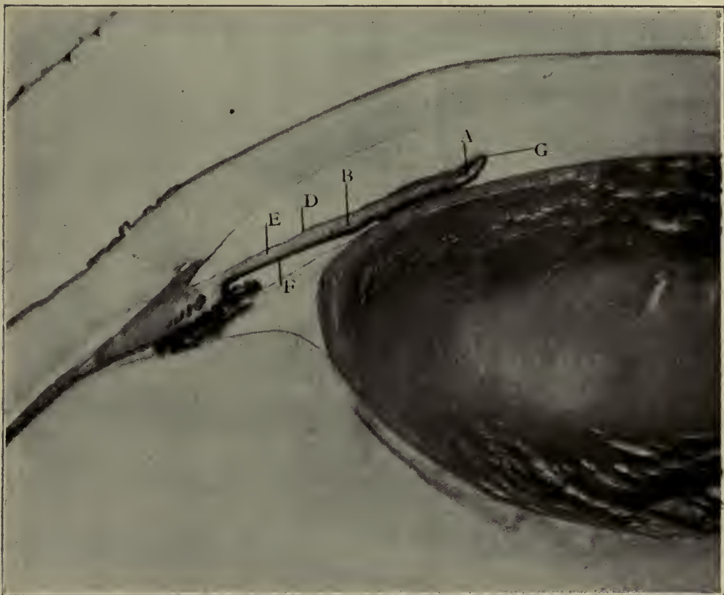

Fig. 65. Showing cross section of Iris, its muscles and layers.

that it hides the blood vessels; therefore, in dark eyes this spokelike appearance is absent.

Lying just behind the iris is found the crystalline lens (pea or lentil), and as the name implies, it is a transparent body shown at A, Fig. 67. This lies in the Fossae Patilaris (dish like depression) in the anterior surface of the

vitreous body and is held in place by the suspensory ligament, B. The lens has two portions, however, not divisible or sharply outlined; the central or nuclear portion and the outer or cortical portion. The central or nuclear portion is more dense than the cortical portion. The nuclear por-

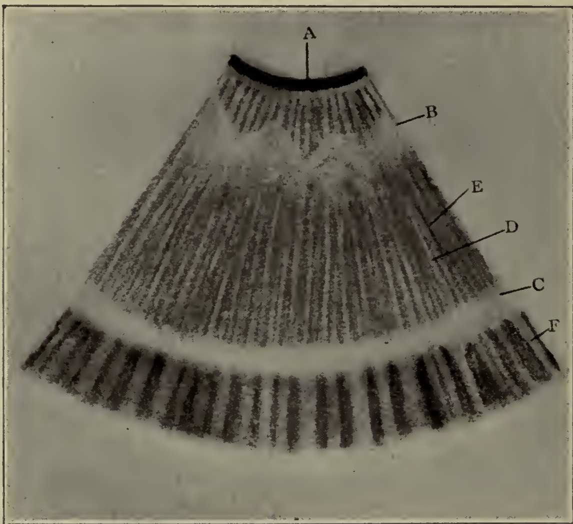

Fig. 66. A quadrant of the front surface of the Iris.

tion is composed of the elongated or spindle cells which first fill the lens vesicle by the elongation of the cells composing the posterior wall of the lens vesicle; see Fig. 8. These cells, as before stated, fill the whole cavity as shown in Fig. 68, D. The nuclei of these cells are pushed forward, as shown at K. After these first formed spindle cells have filled the lens vesicle, then at the transitional (transforming) zone, the original cells of the lens vesicle continue to elongate and grow around the ends of the cells which have formed the nucleus of the lens as shown at J, and in this section the cells, which will form the cortical portion,

are just beginning to grow and elongate. These cells then form the outer or cortical portion of the lens and the ends of the fibers butt together, as shown at A, Fig. 69. These fibers, or spindle cells, have a diamond shape and

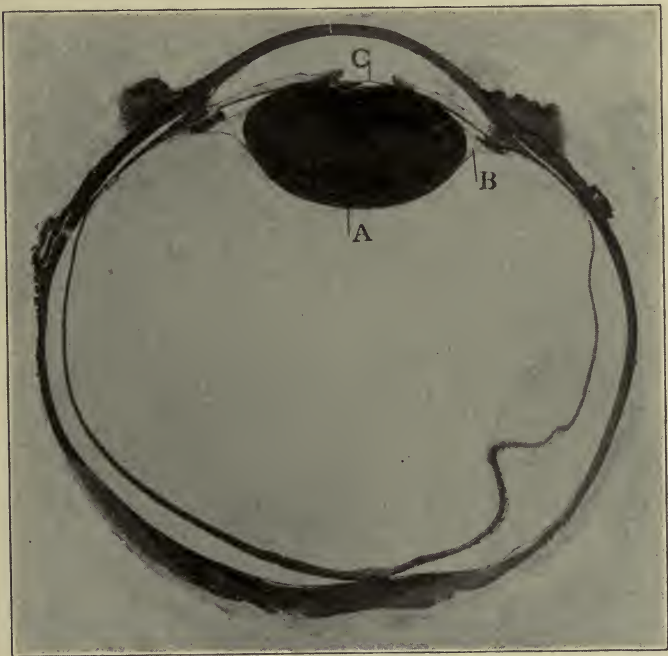

Fig. 67. Cross section of the human eye.

these again are formed in layers bound together by transparent cement substance. These layers are then laid one on another, as the layers of an onion are found, and these layers in turn are bound together by the cement substance. Over the anterior surface of the crystalline lens is formed a single layer of columnar cells, which are the cells composing the original lens vesicle wall. This layer extends back to the equator of the lens and then they become trans-

formed into the spindle cells, which compose the lens substance. The area of transformation is known as the transitional Zone; see G, Fig. 60. Surrounding the whole lens is a thin transparent membrane known as the capsule of the lens, C, Fig. 67, and to this capsule is attached the suspensory ligament, the anterior fibers just in front of the equator and the posterior fibers just behind the equator.

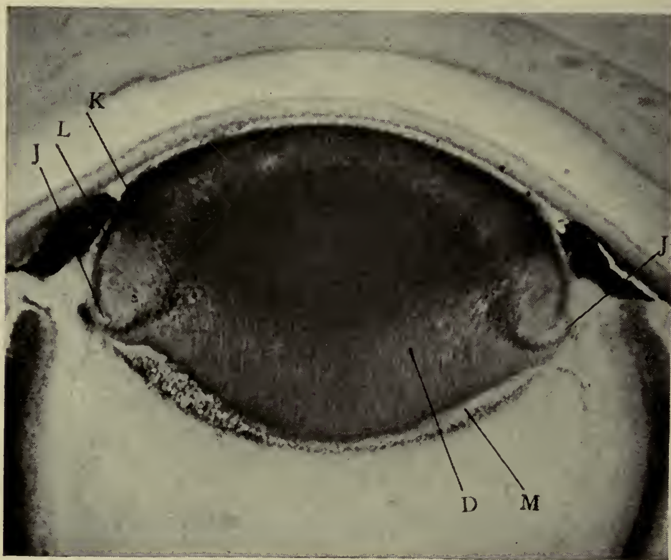

Fig. 68. Human embryo eye, 2 months. Magnified 1,080 times.

The suspensory ligament of the lens or Zonule or Zinn, C and D, Figs. 70 to 74, is imbedded in the outer layer of the hyaloid membrane. This membrane divides into two layers at the ora seratta of the retina (saw tooth mouth), F, Figs. 70 to 74. The inner layer continues over the front of the vitreous body, while the outer layer in which the fibers of the suspensory ligament, I, Figs. 70 to 74, are imbedded, is firmly bound down to the inner surface of the

pars ciliaris retina, ciliary processes and bodies G and H, Figs. 70 to 74. From the ciliary processes, H, the fibers and membrane leave the outer wall of the eyeball and turn transversely across toward the equator of the lens, P. The outer layer of the hyaloid membrane, I, Figs. 70 to 73, becomes very thin and fluid passes through it very readily. It passes across with the fibers of the suspensory

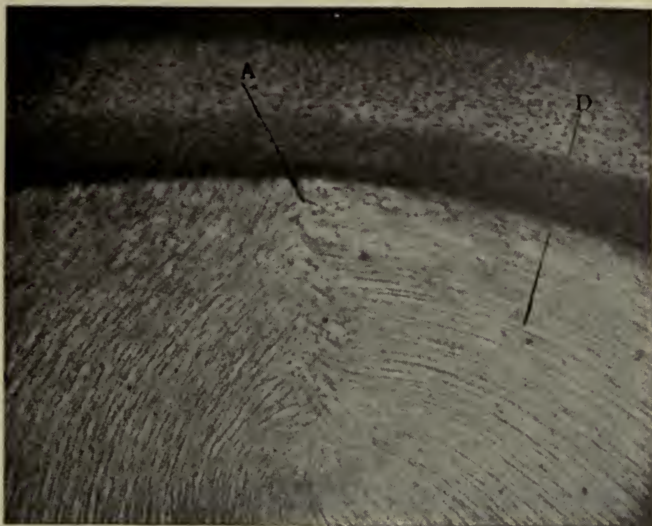

Fig. 69. Human embryo eye, 5 months. Magnified 7,000 times.

ligament, which are attached in front of the equator of the lens, and the triangular space bounded by it in front and the hyaloid membrane behind with its base at the equator of the lens. The apex at the ciliary bodies is called the canal of Petit, E, Figs. 70 to 73.

The fibers of the suspensory ligament, C and D, Figs. 70 to 74, arise from the retina at the ora seratta, F, and are continuous clear to their attachments to the lens, A and B. These fibers are believed to be specialized elongated fibers

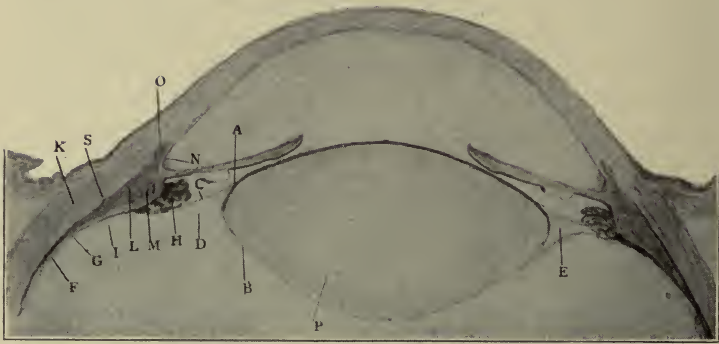

Fig. 70. Showing the suspensory ligament.

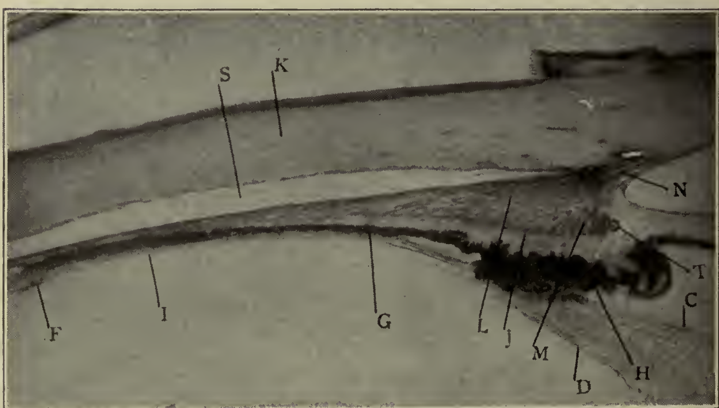

Fig. 71. Showing ora seratta and ciliary processes.

of Mueller, which are of a very elastic nature. These fibers become attached to the lens capsule during the development of the eye and as the eye enlarges become elongated. When they leave the ciliary bodies they divide and a part

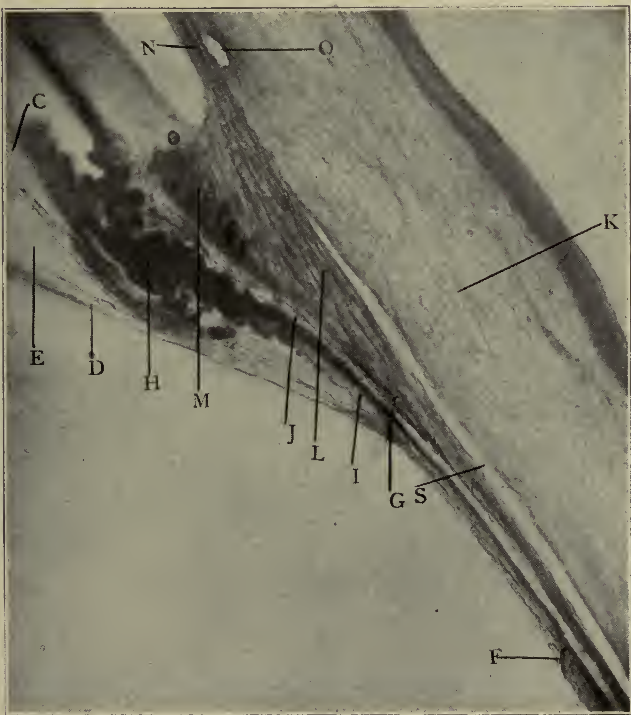

Fig 72. Enlarged view of ciliary muscle.

of them, C, Figs. 70 and 73, pass to their attachment to the lens capsule in front of the equator and others, D, Figs. 70 to 74, pass to their attachment to the lens capsule back of the equator, while a few pass across in the canal of Petit, E, Figs. 70 to 73. These are attached to the lens at

its equator. By glancing at Fig. 70 and noting the attachment of the suspensory ligament, C and D, it will readily be understood that tension on the suspensory ligament, C and D, of the lens, P, Fig. 70, would have a tendency to flatten it in its anterior posterior diameter and enlarge its

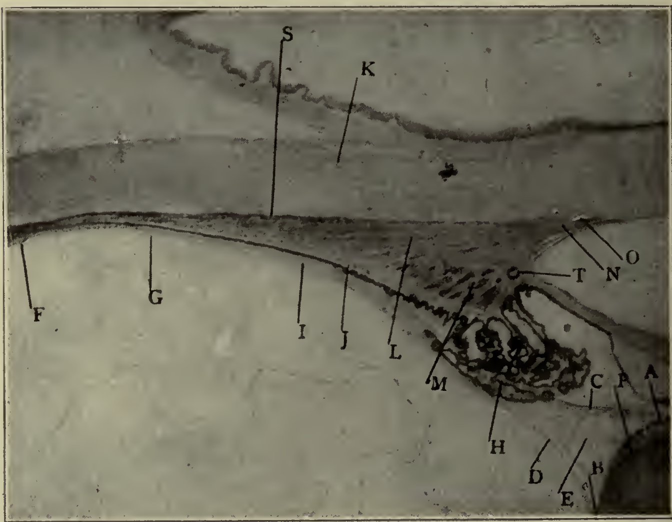

Fig. 73. Showing ciliary processes and bodies.

transverse diameter, thus increasing and decreasing its convexity, as this tension was exerted or relaxed.

Lying between the ciliary processes, bodies and choroid, G, H and I, Figs. 70 to 73, and the sclerotic, K, Figs. 72 and 73, is found the ciliary muscle, L and M, Figs. 70 to 73 (hair-like muscle), composed of plain muscular fibers. It is composed of two portions, the longitudinal or the outer portion, L, Figs. 70 to 73, and the circular portion, M, Figs. 70 to 73. The fibers of the first or outer portion, L, run anterior posterior, arising at the limbus (seam), N,

Figs. 70 and 73, a portion of them in front of and a portion posterior to the canal of Schlemm, O, Figs. 70 and 73. The circular portion, M, has the same origin, but takes a circular course and lies just outside of the ciliary bodies, H, Figs. 70 to 73. The longitudinal fibers are attached to the outer surface of the choroid, J, Figs. 71 to 73. They

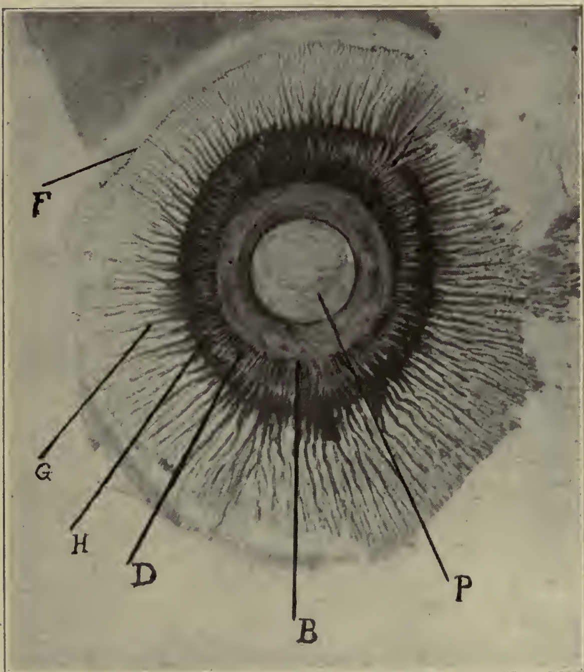

Fig. 74. Suspensory ligaments and lens drawn in.

spread out fan shaped, some being attached as far forward as the posterior ends of the ciliary bodies, H, Figs. 70 to 74. Others extend backward and are attached as far backward as the ora seratta, F, Figs. 70 to 74; thus it is seen they have a very extensive attachment to the choroid. The function of the ciliary muscle is to put the choroid, J,

on the stretch. This is possible owing to the supra choroidal space, Figs. 70 to 73, separating the choroid and sclerotic, and the circular fibers, M, press the ciliary bodies, H, nearer to the equator of the lens, B, Fig. 74. As the suspensory ligament, C and D, is bound down to the choroid ciliary processes and bodies, and bridges across the space between the ciliary bodies, H, and the lens, P, the action of the muscle when it contracts is to slacken the

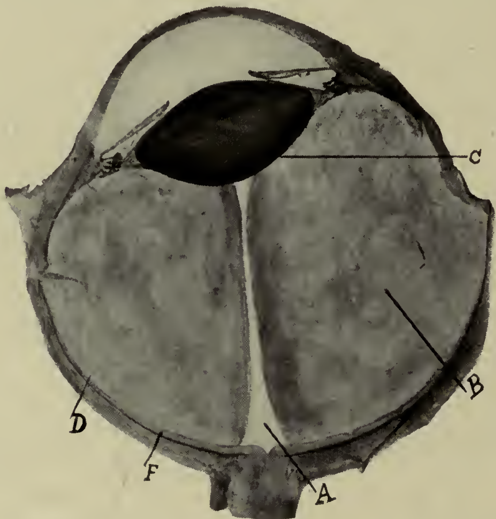

Fig. 75. Vitreous darkened to show hyaloid canal.

suspensory ligament, allowing the lens P to become more convex by virtue of its elasticity or resiliency. However, the main strain in accommodation seems to fall upon the circular portion M in Figs. 70 to 73, from the fact that in myopic eyes where the far point is within thirteen inches of the eye, where accommodation is never necessary, but few if any of these circular fibers are found upon examining the ciliary muscle after death, whereas in the hypermetropic eyes where accommodation is necessary for all

vision, these fibers will be found to be very plentiful. In fact they have been known to make up as much as seventy-five per cent of the bulk of the muscle. The ciliary muscle receives its nerve supply from the posterior ciliary nerves, which arise from the lenticular or ciliary ganglion (to knit or weave), which receives its motor roots from the third cranial or motor oculi nerve. See Figs. 42, 43 and 44. The terminal portions of the posterior ciliary nerves break up into small anastomosing branches and form the ciliary plexus, which lies in the ciliary muscle.

The vitreous body, B, Fig. 75, composes the greater portion of the eyeball, filling all the cavity posterior to the lens. It is composed of shapeless transparent cells, very loosely arranged, so that it resembles a sponge and is filled with fluid resembling the aqueous humor, and is about of the density as the white of an egg, running through the vitreous body. Antero posteriorly from the posterior of the lens to the head of the optic nerve is found a lymph canal, A, Fig. 75, which was the space occupied by the hyaloid artery, which is present during the development of the lens during foetal life. See B, Fig. 16. This canal is known as the hyaloid canal or the canal of Stilling. The lens is imbedded in the anterior surface of the vitreous body, lying in a depression called the Fossae Patellaris (saucer-like depression), C, Fig. 75. The whole body is surrounded by the hyaloid membrane (glass-like membrane), which is transparent and homogenous (structureless), D, Fig. 75. This membrane divides at the ora seratta, F, Figs. 70 to 74, the inner layer covering the anterior of the vitreous and lining the fossae patellaris, C, Fig. 75, while the outer layer is intimately attached to the ciliary processes and bodies and leaves the ciliary bodies and extends to the lens. In this outer layer is imbedded the fibers of the suspensory ligament, I, Figs. 70 to 73. Posterior to the ora seratta the hyaloid membrane is very intimately attached to the retina, F, Fig. 75. This attach-

ment is so firm that when the vitreous body is disturbed the nine innermost layers of the retina are usually detached.

The retina (net) lines the inner wall of the eye ball, it extends, properly speaking, from the head of the optic nerve, M. Fig. 76, to the Ora Serratta (Saw Tooth Mouth) X; however, it is continuous clear to the free margin of

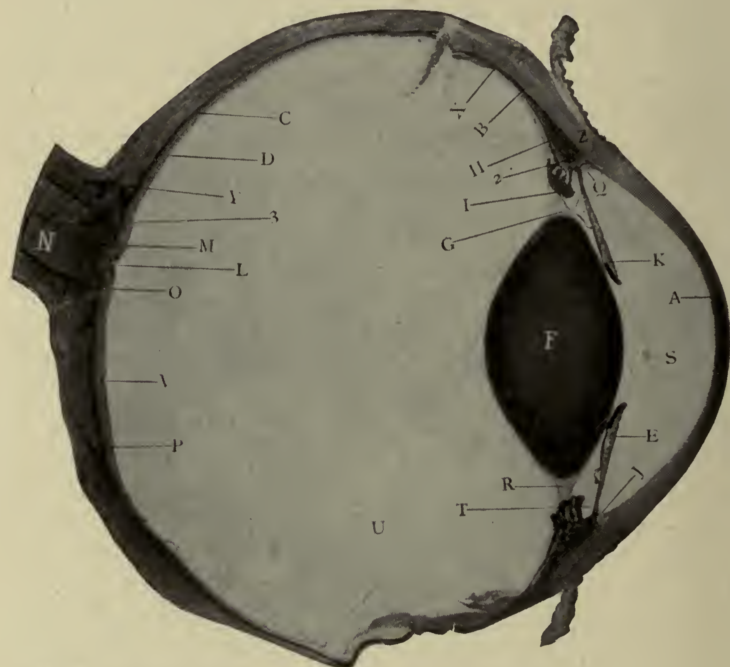

Fig. 76. Cross section of the human eye, showing its construction.

the Iris E, by means of a double layer of pigmented epithelial cells which cover the inner surface of the pars ciliaris retina (the part between the ciliary bodies and the retina), G, Fig. 73, ciliary processes G, Fig. 74, and ciliary bodies H. Figs. 73 and 74, as well as the inner or posterior surface of the iris, E. Fig. 76. This anterior or pigmented portion is called the Uvea (Grape Skin); it is

formed by the continuation forward of the outer or pigment layer of the retina and the anterior portion of the secondary optic vesicle which does not take part in the formation of the nine innermost layers of the retina or more properly speaking, the receiving and transmitting portion of this structure.

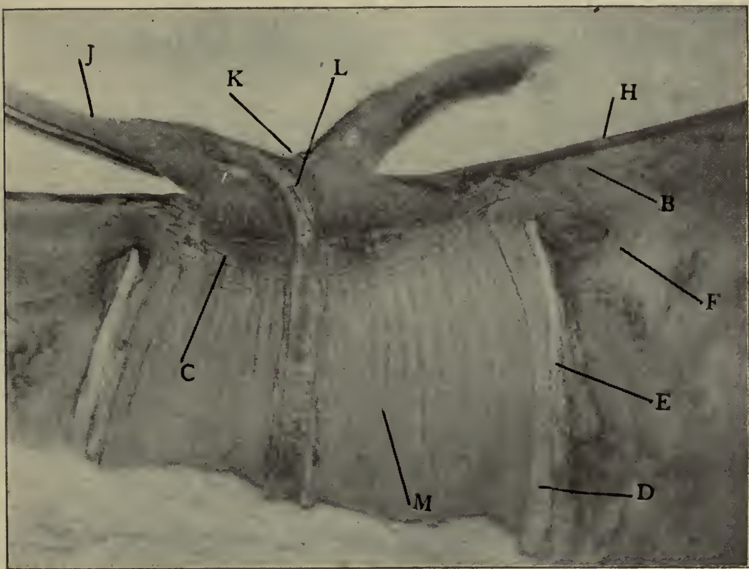

Fig. 77.

The retina is a very thin, delicate structure, being one-half millimeter thick at its thickest portion near the optic nerve, and gradually becoming thinner toward the ora serratta, where it is but one-tenth millimeter thick. It is firmly attached to the choroid at the ora serratta, and is firmly bound down at the head of the optic nerve by virtue of the optic fibers passing from it through the choroidal fissure (the opening of the choroid), L. Fig. 76. There is a less secure attachment at the macula lutea (yellow spot),

J. Fig. 78. In all other portions of the retina the nine innermost layers are very loosely attached to the outer or pigment layer; this attachment is accomplished simply by the interlacing of the rods and cones with the processes which project inward from the cells forming the pigment or outer layer. It is held in place mainly by the interocular pressure.

Fig. 78. Cross section of the Eye, showing its construction.

The retina receives its blood supply from the arteria centralis retina (central artery of the retina) which reaches it through the choroidal fissure after having traversed the optic nerve for some ten millimeters back of the eye ball, L. Fig. 77. This artery is an end artery, or in other words, it is not joined by any other set of arteries, but it sends its branches to all parts of the retina, A. Fig. 78, terminat-

ing in arterial capillaries and turning back as venous capillaries; these keep joining and rejoining and form the vena centralis retina (the central vein of the retina), which leaves the eye ball through the choroidal fissure by the side of the entrance of the artery. See darker vessels in

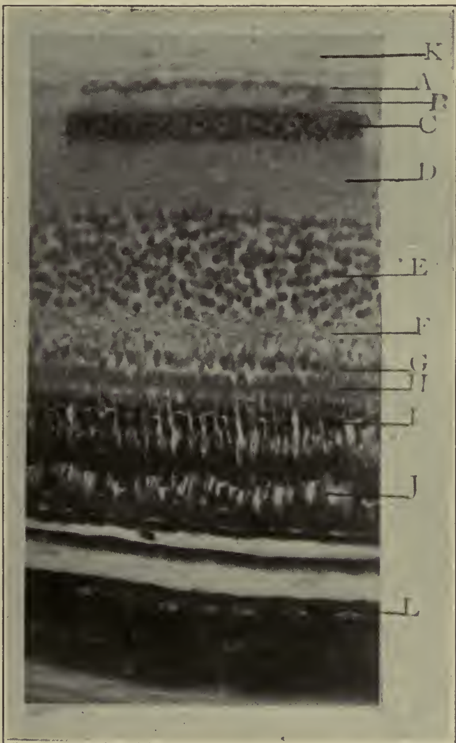

Fig. 79.

Fig. 78. By staining cross sections of the retina it is shown to be divisable into ten layers. Seven of these are nervous tissue, two of neuroglia or nervous connective tissue and one of pigmented epithelium. The nine innermost layers are transparent and are bound together by the fibers

of Mueller, which is the nervous connective tissue of the retina. The outermost or pigmented layer is more intimately attached to the choroid than it is to the other layers.

The layers from within outward are: First, the inner limiting membrane, A. Fig. 79. Second, the layer of nerve fibers, B. Third, the layer of ganglionic cells or ganglionic (knot like) layers, C. Fourth, the inner molecular or plexiform layer, D. Fifth, the inner nuclear or granular layer, E. Sixth, the outer molecular or plexiform layer, F. Seventh, the outer nuclear or granular layer, G. Eighth, the outer limiting layer, H. Ninth, the layer of rods and cones, I. Tenth, the pigment layer, J. K. shows the hyaloid membrane which lies just inside of the retina and L shows the choroid which is the structure just outside of the retina. In this section the choroid is somewhat torn and separated.

The pigment layer, as before stated, is composed of a single layer of columnar epithelial cells which are long hexagonal cells separated from each other by a well defined, clear, cement substance. They have long protoplasmic processes which project inward and interlace with the rods and cones. In these cells are deposited pigment granules which remain in the base or outer portions of the cells when the eye is closed or in darkness. See G, Fig. 80. F is the lamina vitrea or Bruck's membrane of the choroid. However, when the retina is exposed to the light these pigment granules flow into the processes which lie amongst the rods and cones (C, Fig. 81), thus protecting these delicate structures from destruction by too intense light as well as forming a screen right amongst the rods and cones, to receive the image which is formed by the refracting surfaces of the eye. See Fig. 81. A is the choroid, B the bases of the pigment cells and C the processes lying amongst the rods and cones.

The layer of rods and cones (I Fig. 79), especially the cones, are the real sensory cells of the retina, as it is their

function to produce the impulse which is transmitted to the brain and there produces the sense of sight. Each rod and each cone is at the end of a process which comes from a cell in the outer nuclear layer (G, Fig. 79). These pass through openings in the outer limiting membrane (H, Fig.

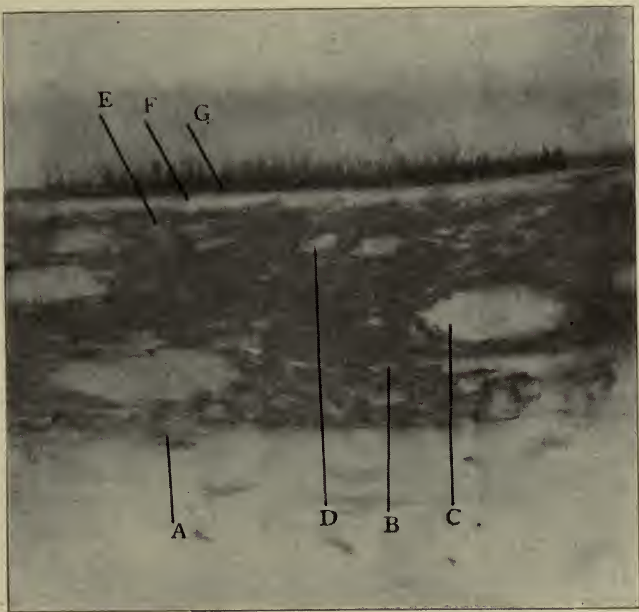

Fig. 80. Showing Section of Choroid.

79). The cones, as their name implies, are of a conical shape, shorter than the rods; they have a large oval inner portion with a finer tapering point extending outward into, and interlacing with the processes extending inward from the pigment layer. The oval or enlarged inner portion is striated longitudinally, while the outer or tapering portion is formed apparently of discs. The rods are long cylindrical cells striated longitudinally, and are divided into two segments at about their middle. Their function is not clearly established. There are estimated to be about

three million cones in the human retina, and the rods exceed this many times. The cones predominate in the macula or most acute area of sight, while the rods predominate in all other portions of the retina, thus proving the cones to be the real sensory elements.

The next layer from without inward is the outer limiting layer. (H, Fig. 79.) This is formed by the overlapping of the flattened ends or feet of the outer extremities

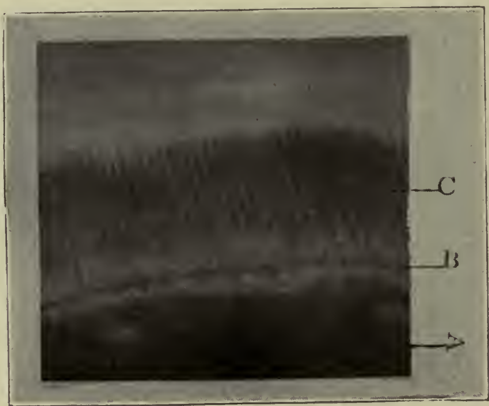

Fig. 81.

of the fibers of Mueller or nervous connective tissue, which will be explained later; this layer is punctured by millions of openings through which pass the processes on the distal ends of which the rods and cones are found. The next layer inside of the outer limiting membrane is the outer nuclear or granular layer. (G, Fig. 79.) It is almost wholly composed of bipolar cells; that is, they have two processes, one runs outward through the outer limiting membrane and ends in a rod or cone, whilst the other runs inward and ends in a brush like end or tuft in the outer molecular layer. The single layer of cells seen just inside of the inner limiting membrane in Fig. 79, are sup-

posed to be the cells connected with the cones whilst the cells connected with the rods lie in the middle and inner portion of this layer. There are several varieties of nerve cells found in this layer, the functions of which are undetermined, and will be omitted in this description. The next innermost layer is the outer molecular or plexiform layer. (F Fig. 79.) This layer is composed of the end arborisations of the bipolar cells in the outer nuclear layer, which run inward, and the distal end tufts on the processes from the bipolar cells in the inner nuclear layer, which run outward, as well as some other nerve cells which have processes which extend to a greater or less extent in this layer. They are known as amacrine (long fiber) cells; their function is undetermined, but they seem to be association elements to join different portions of the same layer.

The next innermost layer is the inner nuclear or granular layer, E, Fig. 79. This layer is mainly formed of bipolar cells; they send one process outward into the outer molecular layer which ends in a brush-like end or tuft interlacing with the tufts on the inner ends of the inner processes from the bipolars of the outer nuclear layer and send another process inward into the inner molecular layer which ends in an end tuft or arborisation. There are other nerve cells in this layer also, the function of which has not been determined. The next innermost layer is the inner molecular or plexiform layer, D, Fig. 79. This, like the outer plexiform layer, is almost wholly composed of the end tufts of the processes from the bipolar cells; however these come from the bipolars in the inner nuclear layer which run inward and the processes which run outward from the ganglionic cells in the ganglionic layer and, as explained about the other cells found in the outer molecular layer, those found in the inner molecular layer have not been thoroughly studied and their functions ascertained farther than that they associate different areas of the same

layer. The next innermost layer is the ganglionic (knot-like) cell layer, C. These cells might well be called relay cells, for they are very large; they send from two to three processes outward into the inner molecular layer from each cell, which form tufts and interlace with the tufts on the inner ends of the processes from the bipolar cells in the inner nuclear layer. It is from these ganglionic cells that the axis cylinder processes grow which form the next innermost layer, which is called the nerve fiber layer, B. These axis cylinder processes are continuous from the ganglion cells of the retina into the nerve fiber layer. They pass out of the eyeball through the choroidal fissure and form the optic nerve, which will be described later, and are continuous from the ganglion cells in the retina to the nuclei at the base of the brain. The next innermost layer is the inner limiting membrane, A. It is formed by the expanded or foot-like inner ends of the fibers of Mueller. The fibers of Mueller are the sustentacular (sustaining or binding) tissue of the retina and are the same as the neuroglia cells found in the brain and spinal cord. They are long, branching, connective tissue cells which extend from the inner to the outer limiting membranes and the overlapping of their expanded, or foot-like, ends form both the inner and outer limiting membranes. Their function is to bind the nine innermost layers of the retina together. The retina becomes quite thin at the macula and the cells which otherwise would occupy the space are piled up around it. The processes from these displaced cells, as well as the fibers of Mueller, run obliquely outward and toward its center.

The optic nerve, M, Figs. 76 and 77, leaves the eyeball at the choroidal fissure (opening through the choroid) and is made up of the axis cylinder processes, which arise from the ganglionic layer of the retina C, Fig. 79, and lie between this layer and the inner limiting membrane, A, forming the nerve fiber layer of the retina B. These nerve

fibers, or axis cylinder processes, pass through the openings in the lamina cribrosa (sieve layer), C, Fig. 77, just back of the choroidal fissure. The fibers are bare, or, in other words, devoid of the myeline (marrow) sheaths or white substance of Swan, until after they pass through the lamina cribrosa (sieve layer). This covering is then added and

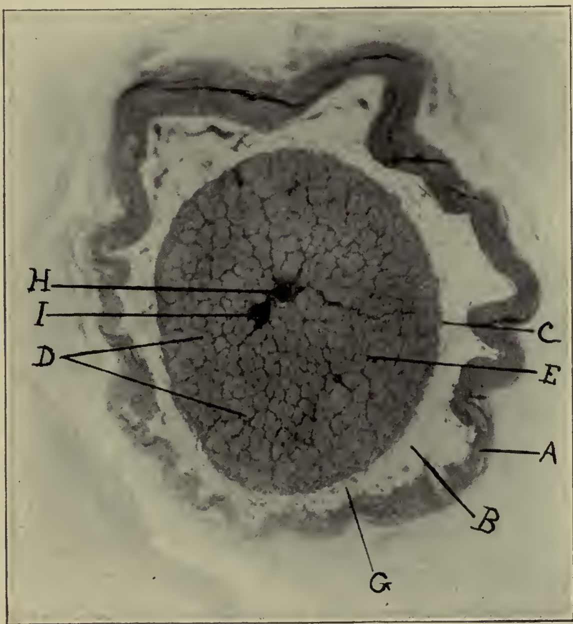

Fig. 82. Cross section of optic nerve showing neuroglia stained dark and nerve fibers light.

this addition adds greatly to the bulk or size of the nerve at the choroidal fissure and at points posterior to the lamina cribrosa. All the fibers which arise from the ganglionic cells in the retina transmit visual impulses toward the brain. However, in the optic nerve are found many fibers which grow from the brain to the retina. These are sensory

fibers of association and carry sensory impulses which cause the closure of the pupil when the retina is exposed to bright light, as well as causing the dilation of the pupil when the eye is in darkness and govern co-ordinate movements of the two eyes.

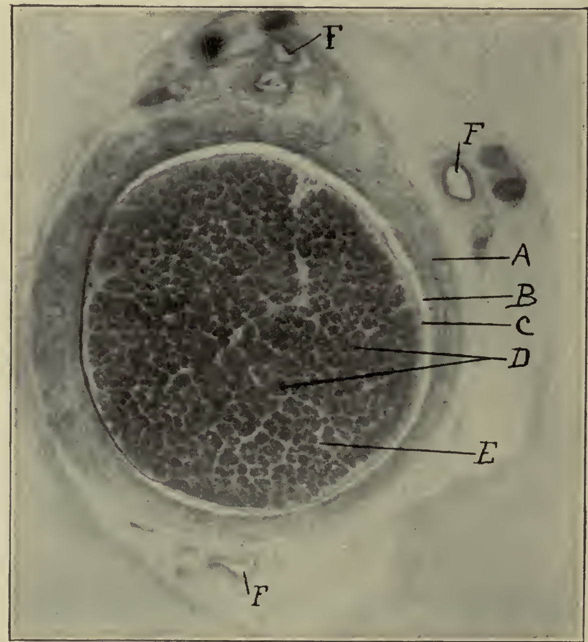

Fig. 83. Cross section of optic nerve showing nerve fibers stained dark and the neuroglia stained light.

The arteria centralis retina (central artery of the retina), L, Fig. 77, B, Fig. 78, and H, Fig. 82, and the vena centralis retinæ (central vein of the retina), I, Fig. 82, and dark vessels in Fig. 78, enter and leave the eyeball with the optic nerve, after entering its substance some ten or twelve millimeters back of the eyeball.

The optic nerve is surrounded by three coverings; the outermost being the optic nerve sheath, A, Figs. 82 and 83, and F, Fig. 77. This covering is formed by the continuation backward around the nerve of the outermost portion of the sclerotic, Y, Fig. 76, and F, Fig. 77. This sheath is continuous backward to the optic foramen (open-

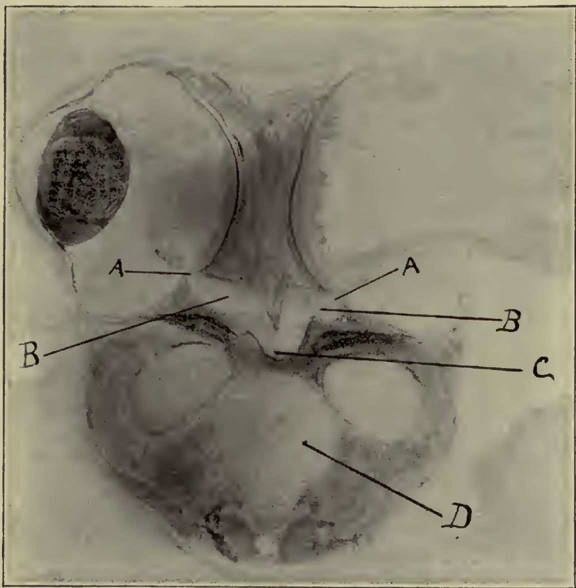

Fig. 84. Showing cross section of the head of a bird,

ing), where it is continuous with the dura mater (hard or firm mother) of the brain. The optic nerve sheath is quite firm and is composed of connective tissue bundles. Beneath the optic nerve sheath is found a space surrounding the nerve which is known as the intervaginal space, E, Fig. 77, and B, Figs. 82 and 83. This space is continuous through the optic foramen with the sub-dural and sub-arachnoidal spaces of the brain, and this intervaginal space is filled with the cerebro spinal fluid.

Lying within the intervaginal space is found the arachnodial sheath (spider web sheath), G. Fig. 82. This is a very thin, web-like membrane, joined quite intimately to the outer and inner sheaths of the optic nerve, by trabeculæ (beams), which cross the intervaginal space.

The innermost covering or sheath is known as the pia mater (thin mother) or pial sheath, D, Fig. 77, and C, Figs. 82 and 83. This is formed of glial tissue (nervous connective tissue) and from it is given off the septa or trabeculæ (beams) which surrounds the bundles of nerve fibers and forms the frame work of the optic nerve and holds it together, E, Figs. 82 and 83, and darker longitudinal striations in M, Fig. 77. The pial sheath and trabeculæ is highly supplied with minute arteries and veins which furnish it with nutrition.

The optic nerve is composed of about eight hundred bundles of medulated (covered with myelin) nerve fibers, D, Figs. 82 and 83, and light longitudinal striations in M, Fig. 77, each bundle being composed of from six to seven hundred axis cylinder processes or nerve fibers, each of which are insulated or covered by the myelin (marrow) sheaths.

The optic nerves, B, Fig. 84, leave the eyeballs, A, Fig. 84, just internal to the posterior poles of the eyeballs, and run obliquely backward and inward through the orbit and pass into the cranial cavity through the optic foramen, then join together and form the optic commissure (uniting band), C, Fig. 84. In the commissure a part of the nerve fibers decussate (cross over) and pass backward in the optic tract of the opposite side, while a portion pass into the optic tract of the same side.

The optic tracts extend from the optic commissure to the base of the brain, where a part of the optic fibers enter the external and internal geniculate (knee-like) bodies, others, the optic thalmus (bed), and the rest go to the anterior corpora quadrigemina (meaning the four bodies).

These latter fibers are supposed to be the sensory association fibers, which communicate with the different centers of the brain and their function is for co-ordinate movements of the two eyes as well as reflex movements and sensibilities, while the optic fibers which enter the other basilar (lower) nuclei (nut) come in contact with the protoplasmic processes of the ganglion (enlarged or swollen) cells in these bodies. From these ganglion cells extend the axis cylinder processes, which run upward and backward through the optic radiations to reach the centers of sight which are situated along the calcarian fissure in the cuniate lobe of the brain, which is located in the posterior or occipital region. It is by the interpretation of the impulses created by the cones in the retina and transmitted through the conducting elements in the retina, optic nerve, optic commissure, optic tracts, external and internal geniculate bodies, optic thalmus, and optic radiations to these centers, that sight is accomplished by man.

The Physiology of Vision

Wm. Borthout.

PREFACE.

These lectures, with the exception of the first and last, were delivered before the Chicago Optical Society. As the members of this society were familiar with the eye as a dioptric mechanism, the subjects of refraction and the errors of refraction were treated very briefly, the time being devoted chiefly to a popular exposition of the sensation of vision.

While the aim has been to present these lectures in as simple a manner as possible, yet it is the author's conviction that popular lectures ought not to depart from the general course of scientific methods; experimentation and observation ought to precede the drawing of conclusions, and knowledge should be obtained at first hand whenever possible. For this reason and also to increase the interest in the subject, a large number of experiments have been introduced. These experiments are of such a simple character that the reader will find little difficulty in performing them.

If these lectures and experiments shall stimulate the reader to a greater interest in the study of the human body, the author shall feel that the aim of these lectures has been accomplished.

Chicago, February 13, 1906. W. D. Z.

LECTURE I.

Spencer defines life as the continuous adjustment of internal to external relations. The external relations of a plant or animal change continually, and some of these changes are of such a nature that unless the organism brings itself into harmony with these changes, its life is in danger. To enable the organism to adjust internal to external relations, it must be informed of the external changes; this is accomplished by sense organs, such as the ear, the eye, etc., which are capable of being stimulated or affected by the changes in the environment. The so-called special sense organs are highly developed organs; they are so highly modified that they are generally stimulated by only one particular kind of stimulus. Thus the ear is usually stimulated only by the sound waves of the air; the eye, by light.

Light is the vibration of ether (see Lecture II). When light waves fall upon a bright surface they are reflected in such a manner that the angle of incidence is equal to the angle of reflection (Fig. 1). This law is true whether the reflecting surface is a plane surface, like an ordinary mirror, or a curved surface like a concave or convex mirror. In tracing the reflected ray from a concave or convex surface it is necessary to remember that the normal (perpendicular) to a spherical surface is the radius extending from the center to the point where the incident beam strikes the surface. This is illustrated in Fig. 2 where x is the center of the reflecting surface ab. Cd is the incident beam striking the surface at d. We may now draw the normal xd and the angle between the lines cd and dx is the angle of incidence. Lay off an equal angle on the other side of dx, this is the angle of reflection, and de is the reflected ray.

Light does not travel with the same velocity in all media; in air it travels at the rate of 186,000 miles per second; in a denser medium, as in glass, its velocity is less. The ratio of the velocity of light in air to that in crown glass is as 3

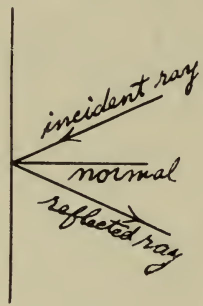

Fig. 1

is to 2; hence light travels 1.5 times as fast in air as in crown glass. For this reason the optical density of crown glass is said to be 1.5.

When light passes from an optically rarer into an optically denser medium, as for example, from air into water or into glass, it is refracted, or bent, toward the normal (per-

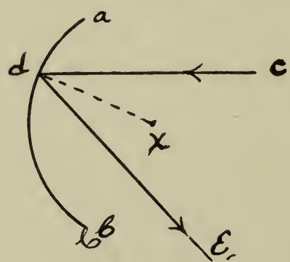

Fig. 2

pendicular), and when it passes from a denser into a rarer medium, it is bent away from the normal. This is illustrated in Fig. 3. The bending of the ray takes place at the surface separating the two media of different optical density; hence this surface is called a refracting surface. A ray of light

that is normal to the refracting surface undergoes no refraction.

The same law holds true when light falls upon a convex lens. Suppose the light comes from an infinite distance; in

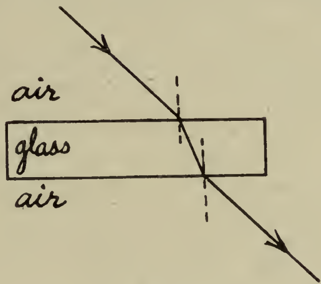

Fig. 3

this case the rays of light may be regarded as parallel. In Fig. 4 let xy be a convex lens and let the centers of the surfaces be located at o and o[1]. The ray ab is normal to both surfaces of the lens (it passes through the two centers) and

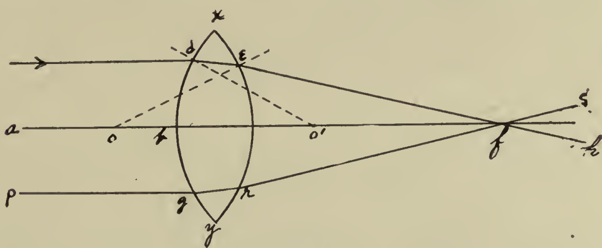

Fig. 4

is therefore not refracted. The ray cd is not normal to the surface and is therefore bent toward the normal (do^1) and describes the course de. The ray de in passing out of the lens meets the posterior refracting surface and is bent away from the normal (eo) and pursues the course eh. In the same manner the ray pq is refracted so that it describes the course rs. It will be noticed that the three rays ab, cd and pq after passing through the lens cross each other at the

point f. This point, where parallel rays come to a focus, is called the principal focus, and the distance between the lens and the principal focus is called the focal length of the lens.

If the source of light is situated at a point nearer than infinity, the rays cannot be considered parallel and the focus of this luminous point lies further away from the lens than the principal focus. In Fig 5 let f be the principal focus. If the source of light is situated at l, the focus is at b. The converse is also true, if b is the luminous point, the focus is at l. Hence the points l and b are called conjugate foci. If the distance from the luminous point l to the lens is twice the focal length of the lens, then the distance between b, the focus, and the lens is also equal to twice the

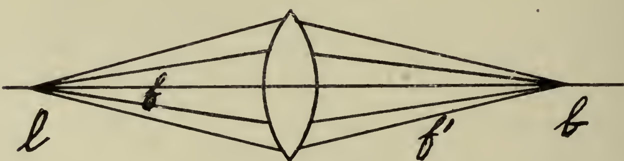

Fig. 5

focal length. As the point l approaches the lens, the distance between b and the lens increases; as l recedes from the lens, b approaches it.

The distance between the lens and the focus of any luminous points can readily be calculated from the formula:

$$\frac{1}{l} + \frac{1}{b} = \frac{1}{f} \text{ or } \frac{1}{b} = \frac{1}{f} - \frac{1}{l}$$

in which f is the focal length, l the distance between the luminous point and the lens, and b the distance between the focus and the lens. Suppose the focal distance of a lens is six centimeters (or inches), and suppose a luminous point is situated ten centimeters (or inches) from the lens; the

distance between the focus of this luminous point and the lens is therefore:

$$\frac{1}{b} = \frac{1}{6} - \frac{1}{10} = \frac{1}{15}$$

that is, b, the distance between lens and focus, is fifteen centimeters (or inches).

From this it is obvious that (a) if the luminous point is at infinity, the focus is at the principal focus; (b) if the luminous point lies nearer to the lens than infinity, but further than the focal distance of the lens, its focus lies somewhere between the principal focus and infinity; (c) if the luminous point is situated at a distance equal to the focal length of the lens, the focus lies at infinity, i. e., the refracted rays are parallel; (d) if the luminous point lies nearer to the lens than the focal distance, the focus lies beyond infinity, that is, it does not exist and the refracted rays are divergent. These four cases are illustrated in Fig. 6 in which F is the principal focus.

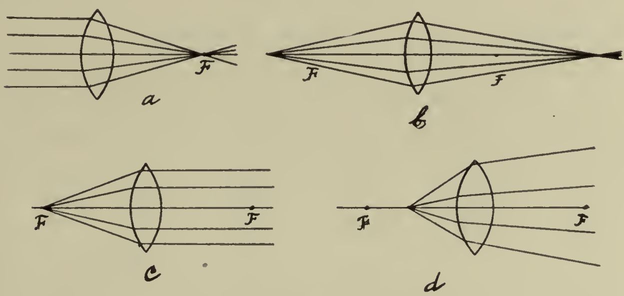

Fig. 6

How can we now determine the location of the focus of any luminous point? In Fig. 7 let f and f^1 be the principal foci of the lens and let l be the luminous point. Draw a ray of light (la) from l parallel with the optical axis. This ray after refraction passes through the principal focus f^1. Again,

take a ray, lc, from l, passing through the principal focus f: after refraction this is parallel with the optical axis. These two refracted rays cross each other at b and this is the position of the focus of the luminous point l. It will be noticed that we can draw a ray from l through the point o which on prolonging meets the other two rays at b; that is, this ray is not refracted. The point o is called the nodal point

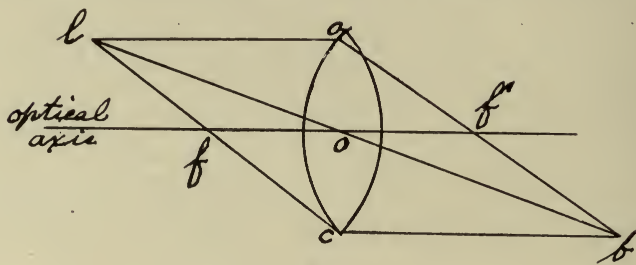

Fig. 7

and may be defined as a point in the lens of such a nature that a ray of light going towards it is not refracted in passing through the lens. If the position of the image of an object is desired, we proceed in the same manner as above. From Fig. 8 it will be seen that the image of a convex lens is a real and inverted image.

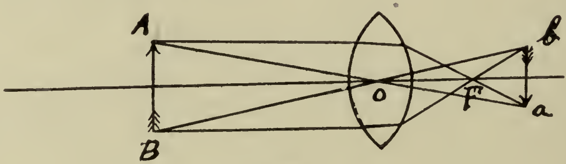

Fig. 8

All convex lenses do not have the same focal distance; that is, they do not have the same refractive power. The greater the optical density of a lens, the greater the refractive power. The density of a medium is called its index of refraction. Again two lenses of the same material and therefore of the same index of refraction, do not necessarily

have the same power of refraction. This depends upon the degree of curvature, or, in better words, upon the radius of curvature; the shorter the radius, the greater the refractive power. Hence the law, the refractive power of a lens varies directly as the index of refraction and inversely as the radius of curvature.

The refractive power of a lens may be stated in terms of its focal length. A lens which has the principal focus 100 centimeters from the lens is said to have one diopter refractive power. If a lens has a focal length of fifty centimeters its refractive power is equal to one hundred divided by fifty, or two diopters. Again, a lens of four diopters has a focal length of one hundred divided by four, or twenty-five centimeters.

We are now ready to consider the eye as an organ of vision. In the eye we have two groups of tissues; first, a group of tissues sensitive to light, and, secondly, tissues by which the rays of light entering the eye are properly focussed on the sensitive tissues. The sensitive tissue is the innermost coat of the eye-ball and is called the retina (See Fig. 14). The media by which the light is focussed are the cornea, the aqueous humor filling the anterior chamber, the crystalline lens, and the vitreous humor (Fig. 14). These media are transparent and, as they have a greater density than air, the light in passing from the air into the eye is refracted. How much the light is refracted depends, as we have stated above, on the indices of refraction of the optical media and on the radii of their curvatures. These values are stated in the following table.

Index of refraction of cornea..........	1.33
Index of refraction of aqueous humor....	1.33
Index of refraction of lens............	1.43
Index of refraction of vitreous humor....	1.33
(Index of refraction of air...........	1.00)

Radius of curvature:

Of anterior surface of cornea	8 mm.
Of anterior surface of aqueous humor	8 mm.
Of anterior surface of lens	10 mm.
Of posterior surface of lens	6 mm.

From the above table it will be noticed that the cornea and the aqueous humor have the same index of refraction; consequently the surface between these two media is not a refracting surface and may be neglected. Between the air and the cornea, between the aqueous humor and the lens, and between the lens and the vitreous humor, we have refracting surfaces at which the light is bent.

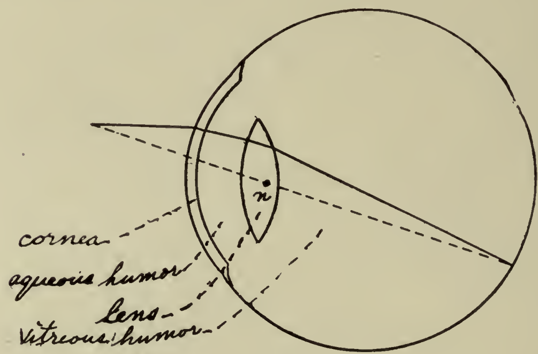

Fig. 9

The general course of the rays in the eye is diagramatically represented in Fig. 9. The rays of light are most refracted at the cornea because of the great difference between the index of refraction of air (1.0) and that of the cornea (1.33). As before stated, the light undergoes no refraction at the posterior surface of the cornea. At the anterior surface of the lens the light is refracted, but not as much as at the cornea for the difference between the density of the aqueous humor (1.33) and that of the lens (1.43) is less than the difference between the density of air (1.0) and

that of the aqueous humor (1.33). Moreover, the radius of curvature of the anterior surface of the lens (10 mm.) is greater than that of the cornea (8 mm.). At the posterior surface of the lens the light is refracted more than at its anterior surface, because the radius of curvature of the posterior surface (6 mm.) is much less than that of the anterior surface (10 mm.).

The refractive power of the cornea is generally stated at about 43 and that of the lens at 15 diopters, making the total refractive power of the eye 58 diopters.

The refracting surfaces and the retina are so placed that in the emmetropic eye (See Lecture II) the posterior principal focus falls on the retina. As the diameter of the eye

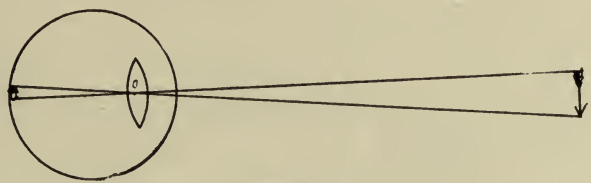

Fig. 10

is about 23 mm., we may say that the posterior principal focal length of the eye (at rest) is about 23 mm. If a point of light is placed at 13 mm. in front of the eye, the rays in the vitreous humor are parallel; that is, the anterior principal focal distance is 13 mm.

The eye also has a nodal point lying near the posterior surface of the lens. To find the position of the image of an object we make use of this nodal point, as is shown in Fig. 10. From this figure it will be noticed that the image on the retina is inverted. If the object lies to the left of the observer, the image of that object lies on the right half of the retina. The size of the image of any object can readily be calculated in the following manner. Let the object be a letter on this page which is about 1/20 or .05 inch tall, and let the distance between the letter and the eye (reckoned

from o, the nodal point, in Fig. 10) be 30 inches. The distance from o to the retina is about 0.6 inch. Hence the size of the image of the letter on the retina will be $\frac{0.05 \times 0.6}{30} = \frac{1}{1000}$ inch.

LECTURE II.

In order to have distinct vision four requisites are necessary: first, a well defined image of the object must be formed on the retina; second, a change in the retina of such a nature that it can be communicated to the endings of the optic nerve; third, the propagation of this change along the optic nerve to the brain; and, lastly, the projection into space of the sensation produced. The first of these requisites will be considered in this lecture.

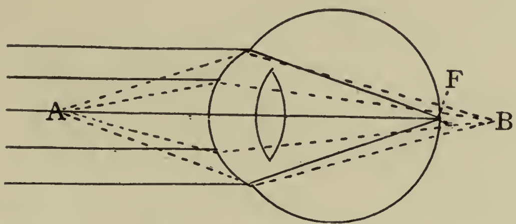

Fig. 11. Diagram showing focus of far (F) and near (B) object when eye is at rest.

You are all familiar with the condition of the emmetropic eye. When the emmetropic eye is at rest, parallel rays of light come to a focus on the retina, at F, in Fig. 11. The rays of light coming from a far off object are regarded as parallel, consequently the emmetropic eye, when at rest, sees distant objects distinctly. The rays coming from a near object are divergent, and divergent rays always come to a focus later than parallel rays. A near object, as the point A, Fig. 11, therefore, has its focus, B, back of the retina and is consequently not seen distinctly. Yet it is a well known fact that a near object can be seen distinctly by the emme-

tropic eye. In order that the near object shall be seen distinctly, a change must be induced in the eye of such a nature that its focus, B, shall fall on the retina. Bringing the focus of a near object upon the retina is called accommodation. How is this produced?

It is interesting to note the various ideas that have been held regarding the power of the emmetropic eye to see near points. We may, first of all, notice the theory of Kepler (A. D. 1600), who held that the lens in viewing near objects moved forward. The further the lens moves forward, the nearer the focus, B, approaches the retina. This process actually takes place in some animals (snakes), but it is not possible for man thus to see near objects, for even if the lens should move as close as possible to the cornea, still the focus of a near object would lie some distance behind the retina. About the same time or a little later, Scheiner put forward the view that accommodation was brought about by the constriction of the pupil. As we shall see in a subsequent lecture, constriction of the pupil renders the vision of near objects more distinct, but it is impossible by mere constriction of the pupil to cause the images of near objects to be as distinct as they ordinarily are during near vision. Besides this, vision of near objects is possible in case of absence of the iris, or in case of a floating iris, or of adherence of the iris to the cornea. Arlt held that accommodation was brought about by the elongation of the eyeball. Theoretically the focus of the near object could thus be brought on to the retina, as the focus is brought on to the plate in a camera. That such a mechanism is not used in the eye is evident from the fact that for the near point the eyeball would have to elongate five millimeters (1-5 inch). The rigidity of the eyeball is sufficient ground for rejecting this view.

It has also been held that vision for near objects was brought about by decreasing the radius of curvature of the cornea; i. e., increasing its convexity. Now decreasing the

radius of curvature increases the refractive power and therefore shortens the focal distance, i. e., the distance between lens and image. Young, in the early part of 1800, proved that the eye does not accommodate in this manner, by showing that accommodation is possible when the eye is submerged in water. If accommodation for a near point was due to changes in the cornea, accommodation could not take place under water for the following reasons.

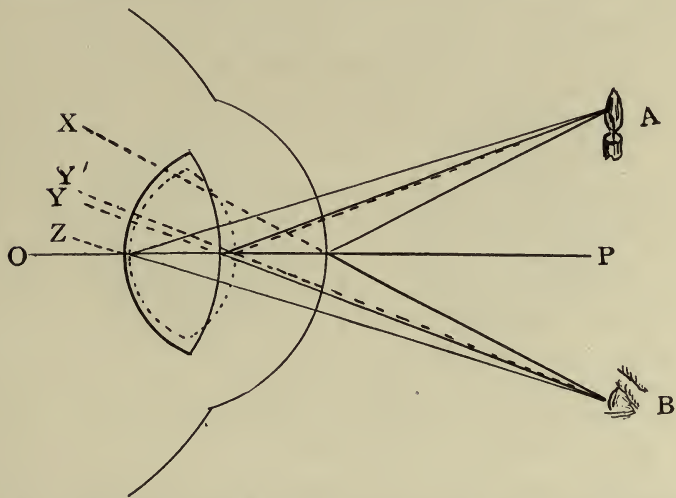

Fig. 12. Diagram showing formation of the Purkinje-Sanson images and their relative position during far and near vision.

In order that a surface (like the anterior surface of the cornea or lens) shall act as a refracting surface, that is, shall have the power to bend the light, it must be the boundary between two media having different densities (or indices of refraction). The indices of refraction (density) of air and cornea are 1 and 1.37 respectively; consequently the light is bent (refracted) when it passes from air into the cornea. As water has an index of 1.33, placing the eye under water destroys the refractive power of the cornea, for it now no longer separates two media of different densities,

and hence no alteration in its curvature could affect the refraction. Young was one of the first to hold that accommodation is due to some change in the lens. To support this idea, he stated the fact that accommodation is impossible in the absence of the lens.

It was finally decided by means of the Purkinje-Sanson images that the changes which occur in the eye during accommodation take place in the lens. The Purkinje-Sanson images are the images of reflection seen in the eye.

Experiment 1.* Hold a candle about four or five inches in front of the bridge of the nose of another person. Look into the eye from the temporal side. By slightly shifting the position of the candle or of your own eye, you will observe three images of the candle. Nearest the nose you will observe a large and very bright image which moves up as you move the candle upward. On the temporal side you will observe a very small, quite bright image which moves contrary to the movement of the candle. In between these is seen a large, very dim and ill defined image which moves in the same direction as the candle is moved. This image is somewhat difficult to find, but a little patience will reveal it. Make this experiment in a dark place and have the observed eye look at a distant object.

These three images are formed by the cornea and by the anterior and posterior surfaces of the lens. In Fig. 12 the line O P is the optical axis upon which lie the centers of the surfaces. A ray of light leaves the candle, A, so as to strike the apex of the cornea; this is reflected into the observer's eye at B, so that he sees an image of the candle. This image he projects into the interior of the eye, as in case of a mirror, and therefore thinks the image situated at X. Another ray of light leaves the candle in such a manner as to strike the anterior surface of the lens (drawn in full line). This ray is also reflected into the ob-

*The experiments described in this series of lectures either were performed during the lecture or are of such a simple nature that they can be performed at home.

server's eye and a second image is supposed to exist at Y. Again, a third ray from the candle goes into the eye and strikes the posterior surface of the lens in such a manner that it is also reflected into the observer's eye. Consequently three images are seen, X, Y, and Z (see Fig. 13A); X being produced by the cornea, Y by the anterior surface, and Z by the posterior surface of the lens. As X and Y are reflected from convex surfaces, these images are erect, as can be seen by moving the candle up and down; Z being formed by a concave surface is inverted, moving in con-

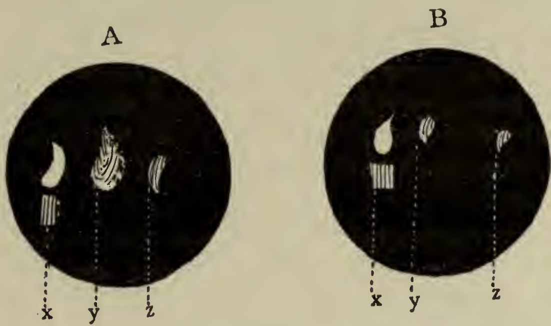

Fig. 13. Showing relative position and size of the three Purkinje-Sanson images; A during far and B during near vision.

trary direction with the candle. Of these three images, X is very bright and rather large; Y is the largest and the dimmest; Z is the smallest. The size of the reflected image varies directly as the radius of curvature of the reflecting surface. The radius of curvature of the cornea is eight millimeters, that of the anterior surface of the lens, when the eye is at rest, is ten millimeters and of the posterior surface six millimeters. Consequently, Z produced by the posterior surface of the lens is the smallest image and Y produced by the anterior surface of the lens is the largest image. If now (in experiment 1) the observed eye accommodates for a near point, it will be noticed that the image Y produced by the anterior surface of the lens approaches

the image X and becomes smaller. Compare Fig. 13A and 13B. These changes in this image can only be explained by assuming that during accommodation the anterior surface of the lens decreases its radius of curvature and approaches the cornea. In Fig. 12 the dotted outline of the lens represents the lens in a condition of near vision. In this case we must take a new ray, the dotted ray, from the candle to the anterior surface of the lens. This ray is also reflected into the observer's eye and the image is projected into the observed eye, so that it is now located at Y′, that is, nearer to X. And as the radius of curvature has also decreased, Y′ will be found to be smaller than Y.

As we stated a moment ago, decreasing the radius of curvature increases the refractive power and shortens the focal distance; consequently the focus of the near point, which, in the resting eye fell behind the retina, B, Fig. 11, now falls on the retina.

The next subject to consider is how this change is produced in the lens. In order to do this intelligently the anatomy of the eye must be studied. The outer coat of the eye is called the sclerotic, Fig. 14. Inside of this is located the choroid, which contains the blood vessels, and inside of this we find the retina, the sensitive layer of the eye. Anteriorly the choroid is thickened, so as to form the iris, Fig. 14, and the ciliary processes. These processes encircle the lens and from them extend the suspensory ligaments by which the lens is held in place. According to the Helmholtz theory, the choroid coat of the eye always has a tendency to be pushed backward. This causes the suspensory ligaments to be drawn taut and consequently, the lens, because of its elasticity, is flattened so that its diameter (thickness) is decreased and the radius of curvature of the anterior surface is increased. In other words, by the traction of the choroid coat, the convexity of the lens is decreased and the refractive power is therefore also decreased. This is the condition of the lens when the eye is

at rest and the emmetropic eye is then able to see far objects.

In the anterior portion of the choroid we find a small group of muscles, called the ciliary muscles. Some of the fibres of these muscles are attached anteriorly to the scler-

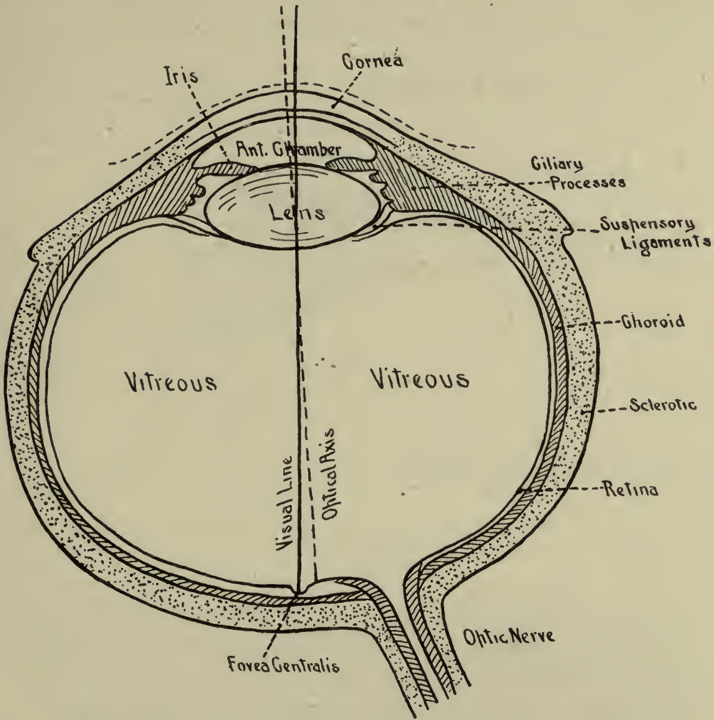

Fig. 14. Diagrammatic section of the left eye.

otic near its union with the cornea, at F, Fig. 15, and posteriorly they lose themselves in the choroid. These fibres run parallel with the sclerotic and are called the meridional fibres of the ciliary muscles. Helmholtz regards the anterior end of these muscles as fixed. Now, when a muscle contracts the two ends of the muscle approach each other;

in fact, this is what we mean by the contraction of a muscle. When the meridional fibres of the ciliary muscles contract, the end G, Fig. 15, approaches the fixed end F, and as the end G is imbedded in the choroid coat, the choroid coat is drawn forward and the suspensory ligaments are thereby relaxed. The lens, as we have stated, is an elastic body and if the pressure to which it is subjected is the same on all sides

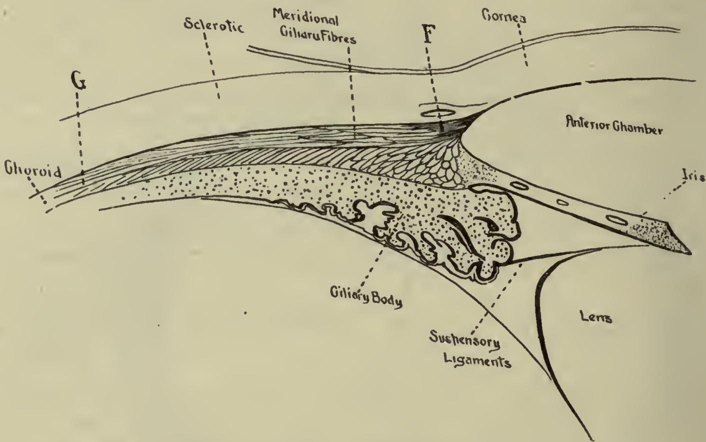

Fig. 15. Diagram showing position of the ciliary muscles. (After Donders.)

it assumes a spherical form. Consequently, when the traction of the suspensory ligaments is removed, the lens by its elasticity assumes a more spherical form, so that the radius of curvature of the anterior surface is decreased from ten millimeters to six millimeters. At the same time the diameter of the lens increases and the anterior surface is brought nearer to the cornea. The changes here described are illustrated in Fig. 16.

The theory of accommodation here given is known as the Helmholtz theory, and while it is not the only theory of accommodation, it is perhaps the best. In support of this theory, we might mention the following facts. If a pin be

stuck in the eye, so as to pierce the sclerotic, the choroid, and the retina, and the animal then accommodates, the head of the pin moves backward; consequently, the internal portion of the pin must have moved forward. This would happen if the choroid is drawn forward during accommodation. It has also been observed that if a piece of the sclerotic coat is cut away so as to form a little window in the eye, the choroid can actually be seen to move forward during accommodation. This has also been observed in the human eye.

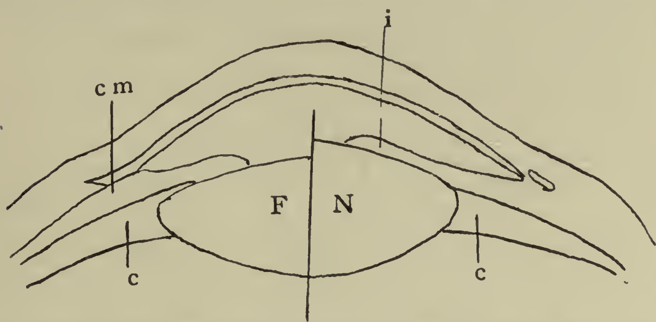

Fig. 16. Changes in the lens during accommodation (after Helmholtz); F, far vision; N, near vision; C, ciliary process; cm, ciliary muscle. i, iris.

Another theory of accommodation is Tscherning's theory. According to Tscherning, the lens is stretched when we accommodate for a near point and is relaxed during far vision. It will be seen that this is diametrically the opposite of the Helmholtz theory. Can it be determined whether the lens is relaxed during far or near vision? I think that by means of the following experiment this question can be answered in favor of the Helmholtz theory.

Experiment 2. Determine the near point for your eye. If no other means are at hand, this can readily be done as follows: Upon a foot ruler place a cork having a groove so that it can slide along the ruler, and stick a small pin into this cork. Now place the end of the ruler against the face, just beneath the eye, bring the cork nearer to

the eye, and determine the nearest point at which the pin can be seen distinctly. Note how many inches this is from the face. Now bend the head forward and determine the nearest point visible. Note the distance. Next bend the head backward and again determine the near point.

On making this experiment carefully, it will be found that the near point in the latter case is farther removed from the eye than in the first case. The reason for this is as follows: During accommodation for the near point, the lens is no longer stretched by the suspensory ligaments and is therefore free to obey the laws of gravity. When the head is

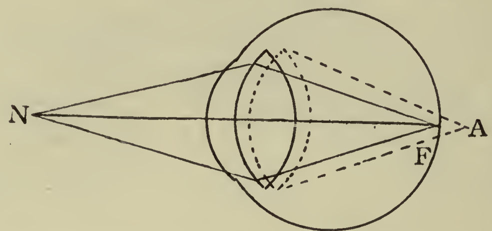

Fig. 17. Diagram showing position of lens during accommodation when the head is bent forward (outline of lens in full) and when the head is bent backward (lens drawn in broken line). In the first case the focus of the near point N falls on the retina (at F). In the latter case it falls behind the retina at A, hence is not seen distinctly.

bent forward, the lens falls toward the cornea, which increases the distance between the lens and the retina; hence a nearer point can be observed than when the head is bent backward, in which case the lens falls toward the retina. See Fig. 17.

A great objection made against the theory of Helmholtz is that in myopes the circular and not the meridional fibres of the ciliary muscles undergo atrophy; in hypermetropes the circular fibres are hypertrophied. This would seem to indicate that the circular fibres are of more importance than the meridional fibres, which cannot be explained satisfactory by the theory of Helmholtz.

Accommodation, as we have seen, depends on the elasticity of the crystalline lens. With advancing age this prop-

erty of the lens becomes less, so that finally the lens changes its shape no longer. In this condition, called presbyopia, or old-sightedness, the near point gradually recedes, as can be seen from the following table:

Age.	Distance of near point.
10 years	7 cm. or 2.76 inches.
20 years	10 cm. or 3.94 inches.
30 years	14 cm. or 5.61 inches.
40 years	22 cm. or 8.66 inches.
50 years	40 cm. or 15.75 inches.
60 years	1 meter or 39.37 inches.
70 years	4 meter or 157.48 inches.

It is evident that if this is the only defect in the eye, it can be remedied by the use of a convex lens used for near work.

Two common defects of vision are myopia and hypermetropia. In myopia, or short-sight, the eyeball is too long and the posterior principal focus (of parallel rays) lies in front of the retina. Hence the resting myopic eye does not see far but relatively near objects, these having the images on the retina. This defect is corrected by a concave lens which delays the focussing of the rays.

The opposite condition, in which the eyeball is too short, obtains in hypermetropia, or long sight; in this the posterior principal focus lies back of the retina and distant objects are not seen distinctly if the eye is at rest. To bring the focus on to the retina a convex lens is used. While the far and near point for the emmetropic eye are infinity and about six inches respectively, in myopia these points lie nearer to the eye, while in hypermetropia they are further removed.

A defect said to exist in all eyes is astigmatism. In the theoretical eye that we have discussed in this lecture, the refracting surfaces are supposed to be segments of spheres; in other words, the various meridians of each surface have

the same radii of curvature. In reality this condition never obtains, but the cornea, for example, has a shape somewhat like the back of a spoon. It is evident that the light will be bent most along the meridian which has the shortest radius of curvature and therefore a luminous point will not have as its image a point but a figure more or less like an ellipse. If the difference in the radii of curvature is great (greater than one diopter), the astigmatism is pathological. In this condition the person is unable to see horizontal and vertical lines distinctly at the same time; this seriously interferes with distinct vision and must be corrected by cylindrical concave or convex glasses.

It has been claimed by some that unequal accommodation for the two eyes is possible. In other words, that we can accommodate more with one eye than with the other. Scientific experiments with the stereoscope have proved, however, that this is impossible; the two eyes always accommodate to the same extent. It is also held by some that the various portions of the lens can be brought into various states of accommodation (astigmatic accommodation). By this means it would be possible to obviate the indistinct vision of astigmatism, for by astigmatic accommodation the astigmatic patient could produce deformities in the lens of such a nature that the original astigmatism would be abolished. The results of the latest investigation are contrary to this view.

LECTURE III.

At the beginning of the previous lecture, we stated that one of the necessary conditions for vision is the formation of a distinct image of the object on the retina. It is a well-known fact that the posterior principal focus of a perfectly homogenous spherical lens is not a point, but a line. This is due to the fact that peripheral rays, A and A, Fig. 18, come to a focus sooner than the central rays, C and C.

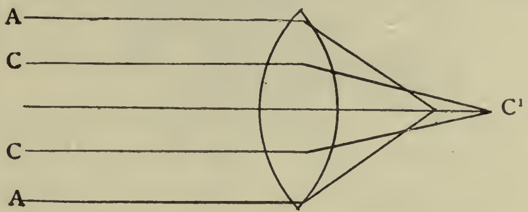

Fig. 18. Diagram illustrating spherical aberration.

This is called spherical aberration. It is evident that in this condition the image cast upon the screen or retina is not distinct, for the focus of the central rays at C′ will be surrounded by circles of diffusion caused by the peripheral rays. Suppose that the object from which the rays emanate is a point; its focus will not be a point but a circle, the size of which varies with the amount of spherical aberration of the lens. Hence the image of the luminous point is blurred. This defect is remedied in our eye in perhaps two or three ways, but the important one is by means of the iris.

Experiment 3. Look into the eye of another person and observe the size of the pupil. When this person looks at a distant object the pupil is large; on accommodating for a near point the pupil becomes much smaller.

This experiment indicates that the size of the pupil varies and is smaller for near vision. The iris always cuts off some of the peripheral rays which by coming to a focus sooner than the central rays would cause blurring of the image on the retina, but it is especially during near vision that the iris is most constricted. The object of this is as follows: The nearer the luminous point approaches the eye, the greater is the distance between the focus of the central and peripheral rays; in other words, the greater the divergency of the rays, the greater the spherical aberration and the greater the need for a small pupil. As near vision is always associated with more divergent rays, near vision must also be accompanied by pupil constriction in order to produce a clear image. The human eye is so constructed that it is impossible for us to accommodate without causing pupil constriction at the same time.

Experiment 4. Look into the right eye of a person and have the left eye covered. Notice the size of the pupil of the open eye; now uncover the left eye and notice that the pupil of the right eye constricts.

Experiment 5. Observe the pupil of a person in very dimly lighted room; now let him walk into a bright light and the pupil will be seen to constrict. On re-entering the darker room, the pupil dilates.

These experiments teach that the size of the pupil depends upon the amount of light entering the eye. Besides this, there are other conditions in which the pupil of the eye is constricted or dilated, which we may summarize as follows: Constriction of the pupil is brought about by bright light, near vision, convergence of the eyes, sleep, and certain drugs; dilation of the pupil is brought about by dim light, far vision, less convergence of the eyes, pain, fright, dyspnoea, and certain drugs.

The pupil dilation and constriction, brought about by light, is said to be a reflex action, and in order to understand this phenomenon, it is necessary that we know what

is meant in general by the term reflex action. The amoeba, Fig. 19, is a lowly organized animal found in pools of water, and is microscopic in size. In the amoeba there is no differentiation of tissue, such as we find in the more highly organized animals, the whole body being composed of only one material, the living tissue, called protoplasm. If the amoeba is stuck with a pin at A, Fig. 19, it responds to this change in its surroundings by moving away from the point A. Instead of applying a pin to the body of the

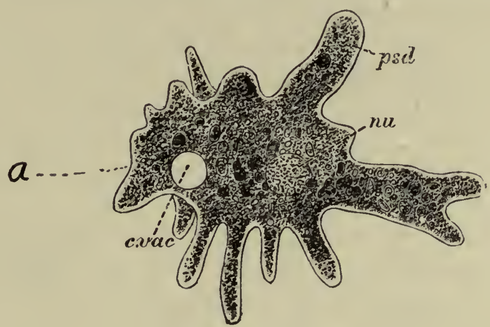

Fig. 19

amoeba, we might have applied heat, an electrical shock, or a chemical agent; all these agencies are changes in the environment of the animal, and are called stimuli. On the application of a stimulus the animal responds to it by some change in its body; this power to respond to a stimulus is called irritability.

In the amoeba the part of the body which receives the stimulus and the part which responds to the stimulus are similar in structure; in fact, the part receiving the stimulus may also respond to it. In this organism there is no physiological differentiation, that is, there is no division of labor. In the more highly developed organisms, like the human body, the responding and receiving organ are not one and the same organ, nor are they necessarily located in the same part of the body. For example, when I touch a hot object

with my finger, I withdraw my hand. In this case the receiving organs are the nerve endings in the skin, while the responding organs are the muscles in the arm. In order that the reception of the stimulus in the receiving organ shall call forth a response in the muscles, a connection must exist between these two organs. This connection is formed by nerves. The physiological functions of nerves are irritability and conductivity, by which the effect of the stimulus on the receiving organs (nerve endings) is conducted to the muscles.

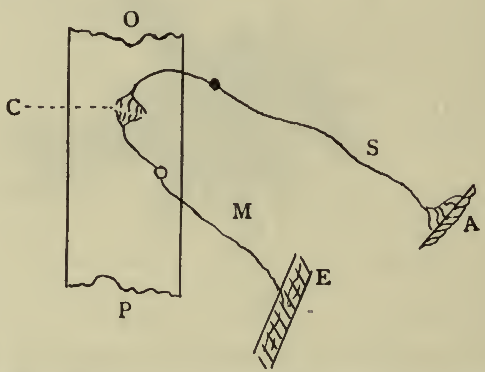

Fig. 20. Scheme of reflex arc. O P is part of the spinal cord; S and M are sensory and motor nerves respectively; A, skin; E, muscle; C, centre in cord where sensory and motor nerves come in contact.

This relationship between the receiving and the responding organs can be gathered from Fig. 20. In this figure let A be a piece of skin in which the nerve S has its endings. This nerve goes to the central nervous system, that is, to the spinal cord or to the brain. In the cord or brain this nerve ends and its endings come in close contact with the endings of another nerve (at C, in Fig. 20), which leaves the spinal cord and supplies the muscle, E. The stimulus applied at A generates a nerve-impulse which is carried by the nerve S to the spinal cord, leaves the cord by the nerve M and is carried to the muscle, causing this to contract.

Such an action is called a reflex action. The nerve S which carries the nerve impulse to the central nervous system is called a sensory, or centripetal, nerve; the nerve M which carries the impulse from the central nervous system to the responding organ, as a muscle, is called a motor nerve, or better, centrifugal nerve. The spot in the central nervous system where the endings of the sensory and motor nerve come in contact is called a reflex center. In order that a reflex action shall take place, it is evident that both sensory and motor nerves must be intact.

For a reflex action, the will or consciousness is not necessary, for many reflex actions take place during sleep. To show this still more plainly we may take the following. When a frog is decapitated, it certainly has lost all psychical functions, such as memory, consciousness, and will, granting that the frog had these faculties before it was decapitated. If such a decapitated frog is suspended and a bit of blotting paper soaked with an acid is placed on its thigh, the frog will draw up one of its hind legs and wipe away the irritating substance, definitely locating it on its body. Hence this action, which is true reflex action, is produced without the intervention of any psychical function. This action is rendered impossible if either the sensory nerve leading from the skin or the motor nerve supplying the muscle is cut. If the spinal cord is destroyed, the action also stops, because the connection between sensory and motor nerves is thereby destroyed, and the impulse sent by the sensory nerves cannot be transferred to the motor nerve.

Now the pupil constriction which takes place during bright light is similar in nature to the actions here described. It is a true reflex action and can take place even in opposition to the will, for we cannot by the exercise of this faculty prevent the constriction of the pupil.

The next question, then, is to determine the pathway of the impulse producing this action, in other words, to determine the sensory and motor nerves concerned in pupil

constriction. It has been found that if the retina, in which the sensory nerve endings of the optic nerve are situated, is diseased, or if the optic nerve, the second cranial nerve, is cut, the constriction of the pupil in bright light no longer takes place. Consequently we regard the optic nerve as the sensory nerve of this pupil reflex. Again, it has been found that if the third cranial nerve, the oculo-motor nerve, is cut, the pupil reflex also disappears, while if the peripheral end of the cut third cranial nerve, i. e., the end attached to the eye, is stimulated, constriction follows. From this it is apparent that the sensory and motor nerves of the pupil reflex are the second and third cranial nerves respectively.

The pupil reflex has been used as a means to determine blindness. If one eye is blind to light, no pupil constriction takes place in this eye when a bright light is cast into it. But in making this experiment, it is absolutely necessary to exclude the light from the sound eye, for it has been found that when a light is cast into one eye, the pupil of the other eye also constricts, even though it be in darkness. This is known as consensual pupil reflex and is due to the partial decussation of the optic fibers, as shown in Fig. 21. Let L E and R E represent the retina of the left and right eye respectively. The external fibers (broken lines in Fig. 21) from the left eye proceed to the left side of the brain, L O, and the external fibers of the right eye proceed to the right side of the brain, R O; but the internal fibers (full lines in Fig. 21) of the left eye cross over to the right side, while the internal fibers of the right eye cross over to the left side of the brain. Consequently, light falling upon the left eye affects not only the left but also the right side of the brain and the nerve impulse is carried to the pupil constricting center for each eye and from thence is sent to both irises. The constricting center is situated in the anterior corpora quadrigemina of the brain.

We must now discuss the responding organ in the iris itself. What structure in the iris causes constriction or dila-

tion upon stimulation of the retina by light? It was stated in the second lecture that the iris is a continuation of the choroid. In the iris are found two sets of muscles; the

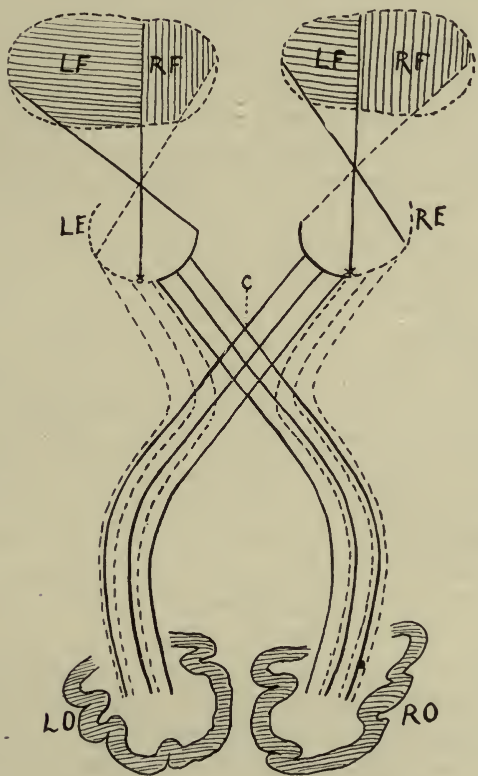

Fig. 21. Diagram illustrating the decussation of optic nerves; LE, left eye; RE, right eye; LO left cerebral hemisphere; RO right cerebral hemisphere; C, chiasma.

fibers of one set having a circular course (parallel with the pupil), the others have a radial course, extending from the periphery towards the central part of the iris. These are called the circular and the radial fibers of the iris. When the circular fibers contract, the pupil constricts; contraction

of the radial fibers causes dilation of pupil. The third cranial nerve governs the circular fibers and consequently stimulation of this nerve is followed by the contraction of the circular fibers, which causes the pupil to become smaller. The radial fibers of the iris are under the influence of the cervical sympathetic nerve and painful stimulation of almost any part of the body is followed by a dilation of the pupil, the impulse being carried to the pupil over the sympathetic nerve. Mental conditions, as I have already stated, also influence the pupil; fright, for example, causes dilation.

Among the many drugs which influence the pupil, we may first of all mention the myotics, such as opium, ether, and physostigmin or eserin, which cause constriction of the pupil. Among the drugs causing dilation of the pupil are atropin and cocaine; these drugs are called mydriatics. Atropin causes dilation of the pupil by paralyzing the endings of the third cranial nerve and consequently light falling into an eye treated with this drug causes no constriction. It must also be borne in mind that atropin causes paralysis of the muscles of accommodation for the same reason, hence an eye treated with atropin cannot accommodate for near objects. We may also mention that alcohol dilates and morphine constricts the pupil.

We may still refer to the curious phenomenon of the rythmical dilation and constriction of the pupil depending upon the heart beat. If you attentively observe the pupil of your neighbor's eye, you may see very limited constrictions and dilations following each other and coinciding with the heart beat, as can be ascertained by feeling his pulse. This is observed better if the pupil is magnified by means of a convex lens.

The constriction and the dilation of the pupil can be seen entoptically in one's own eye. By entoptical perception we mean seeing objects located in the eye itself. A great variety of things can be seen in the eye by the person him-

self, and the principle upon which most of these entoptical visions are based is as follows. In Fig. 22, let the eye be emmetropic and the muscles of accommodation relaxed as in far vision. In the plane of the anterior principal focus, which is located about one-half inch in front of the eye, is placed a cardboard with a small pinhole. The daylight streaming through this pinhole leaves it divergingly, the result being the same as if the source of light was situated in the pinhole, that is, in the anterior principal focus of the eye. If the light is situated in the anterior principal focus of an optical system, the rays after refraction are parallel.

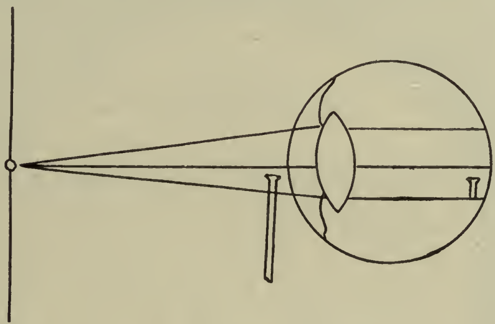

Fig. 22. Illustrating entoptical vision.

Consequently, in Fig. 22 the rays after passing through the lens are parallel with the optical axis and a certain portion of the retina is illuminated. The size of the luminous circle on the retina is determined by the size of the pupil. The larger the pupil, the larger the circle; the smaller the pupil, the smaller the area of the retina illuminated.

Experiment 6. Place the cardboard with a pinhole in the plane of the anterior principal focus of the eye (one-half inch in front of the eye) and look through the pinhole at the bright sky. A luminous circle is seen. Now introduce a pin from below upwards between the cardboard and the eye, as illustrated in Fig. 22. A shadow of the pin is seen. This shadow is formed on the lower part of the

retina, but to the experimenter, the shadow appears to proceed from above downward. The reason for this reversal we will learn later on, but we may here state that, as the eye behaves similar to a simple convex lens, the images on the retina are always inverted.

LECTURE IV.

In the last lecture we discussed the principle upon which most entoptical perceptions are based. By placing a cardboard with a pinhole in the anterior principal focus, a luminous circle is cast upon the retina, and an opaque body situ-

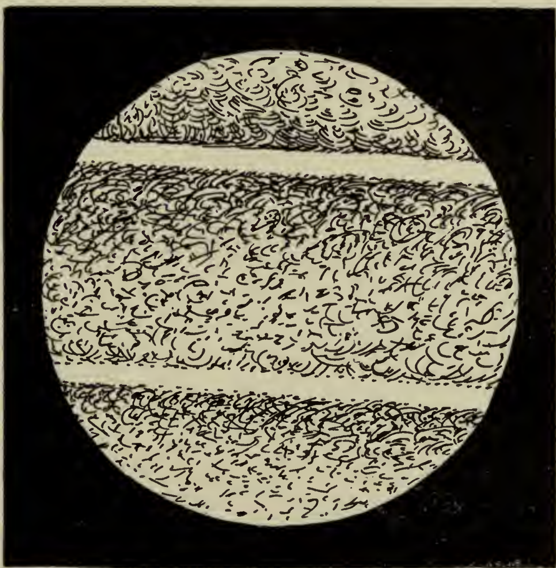

Fig. 23. Striae produced by winking the eyelids (after George Bul)

ated between the pinhole and the retina casts a shadow upon the retina which can be perceived. In this manner we observed the shadow of a pin placed between the eye and the cardboard (see Exp. 6 and Fig. 22). But in entoptical perception the bodies seen are situated in the eye itself.

Experiment 7. While the cardboard with the pinhole is in the anterior principal focus, and the eye looks through the hole at the bright sky, close the eyelid and you will see a field somewhat like that pictured in Fig. 23. The horizontal striations are due to the fact that in pressing the eyelid downward, you have collected the tears and they reflect the light and center it more on the retina. It has also been suggested that the striations are due to wrinkles of the epithelial layer of the cornea caused by the movements of the lid.

Another phenomenon that can be observed entoptically is the changes in the size of the pupil during accommodation.

Experiment 8. As in the previous experiment look at the sky through the pinhole. The luminous circle has a certain size. Now place a pin about eight or ten inches in front of the card and fix your vision upon this. While doing so, the luminous field becomes smaller. Again relax your accommodation, i. e., look at the sky, and the circle increases in size.

This change in the size of the luminous circle is due to the constriction of the pupil which accompanies accommodation for a near point. The constriction of the pupil in bright light (see Lecture III) can also be observed entoptically.

Experiment 9. Face a well-lighted window, close one eye and look through the pinhole with the other eye. The luminous field has a certain size. Now open the other eye; the size of the circle becomes smaller, due to the constriction of the pupil.

In a similar manner, the condition of the crystalline lens can be studied.

Experiment 10. Use a very small pinhole, place the card in the anterior principal focus, and look at a uniform surface, as the sky. A grayish field with a star-shaped figure (Fig. 24) will be seen. Scattered here and there you will also observe small spherical bodies, some lighter and some

darker than the field. The stellate figure is due to the cement substance of the lens. The crystalline lens, as you may know, is composed of a number of layers, somewhat

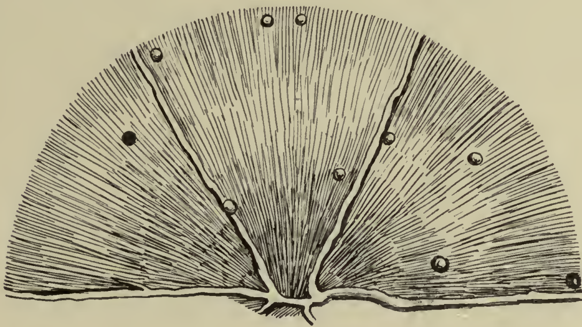

Fig. 24. Diagram representing half of the lens as seen entoptically. (After Donders.)

like an onion; these layers, however, do not form complete semi-circles but have a course which can best be understood from Fig. 25. The ends of the layers are joined by a cement-like substance, and it is this substance that gives rise to the stellate figure seen in Exp. 10. The light and dark spot seen in Exp. 10 are due to small imperfections of the lens which have been observed microscopically in the lens. If the lens were perfectly homogeneous, i. e., composed of one material, you would not observe these things. As a person grows older, these imperfections of the lens increase and the stellate figure may become black; this may in part be the cause of the diminished acuteness of vision in old age.

A group of bodies in the eye most frequently observed are the muscae-volitantes, or flies. These muscae-volitantes can be readily seen by looking at the bright sky, but by means of the following experiment they become more distinct.

Experiment 11. Place the cardboard, as in Exp. 10, but use a large hole. Look at the sky and you will see scat-

tered over the field little disks. Sometimes you will see them as single disks, sometimes they are in strings or groups, Fig. 26. If you fix a certain point in the sky, you will notice that the muscae are always floating downward. Try to fix your line of vision upon one, and it evades you; for this reason they are called muscae-volitantes, or flying flies.

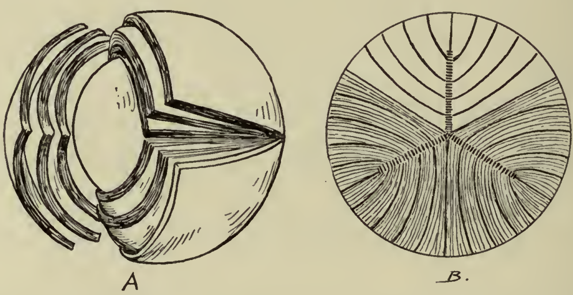

Fig. 25. A, Laminated structure of the crystalline lens, showing the denser nucleus and the concentric outer layers. B, Diagram showing arrangement of lens fibres (posterior view.)

Ordinarily we do not see these flies, but when the light enters our eye in such a manner that these bodies cast a strong shadow upon the retina, we become conscious of them. Some of these muscae are very permanent. Naturally you ask what are these bodies. Donders found that these muscae-volitantes are imperfections in the vitreous humor, which have a greater or a lesser refracting power than the vitreous humor itself. They are said to become more numerous in myopes, some myopes being so troubled with them that the anxiety caused by them becomes a case of monomania.

Still another phenomenon that can be seen entoptically is the phosphene.

Experiment 12. With the tip of the finger press the corner of the eyeball. Notice in the opposite side of the visual field a dark disk surrounded by a very light band. That which is seen when the cornea is thus pressed is called

a phosphene, and is caused by the mechanical stimulation of the retina. Something similar to this can be seen by rubbing the closed eyes with the knuckles. A most beautiful display of colors in ever varying pattern, very much like the field seen in a kaleidoscope, presents itself.

Besides these, we can also observe the blood-vessels in our own eye. In a certain layer of the retina are located the blood-vessels which supply the retina, and if the light falls into the eye in a strange fashion the shadows of these vessels are seen.

Fig. 26. Muscae Volitantes.

Experiment 13. In a dark room hold a candle quite close to the eye, and a little to the right, when you are experimenting with the right eye. By moving the candle to and fro you will see depicted upon an orange field a beautiful display of blue lines which branch again and again.

These are the blood-vessels. They always cast shadows on the retina and yet we are never conscious of them. Why we do not see them ordinarily is perhaps difficult to explain, but we may say that what we always see we never see, or, more correctly, images that are constantly on the retina (like the shadows of these blood-vessels) no longer affect our consciousness. A stimulus is a *change* in our environment; we are only conscious of changes. Hence, when the position of the shadows of the retinal vessels is changed, then, and then only, do we perceive them. This is accomplished by letting the light enter the eye from a different direction than it normally does.

Not only can the blood-vessels of the retina be seen entoptically, but even the blood streaming through these vessels can be thus observed.

Experiment 14. Hold a piece of blue glass in front of the eye and look steadily at the bright sky. Numerous little light spots will be seen crossing the field in tortuous lines. The specks appear and disappear very suddenly and are immediately followed by others, their motion reminding one very much of the skating of certain water-beetles on the surface of the water. After looking at them for sometime, you can trace out the definite paths they follow.

It is perhaps well known to you that in the blood we find an innumerable number of microscopical disks called red blood-corpuscles. Now the light specks that you observed in the previous experiment are these corpuscles floating in the blood as it flows through the retinal vessels. It is supposed that the corpuscles in flowing through the retina stimulate the retina mechanically, very much the same as you did in Experiment 12, and hence they appear as luminous circles.

Before we dismiss the subject of entoptical vision, I must call your attention to one more phenomenon, closely related to this subject. On entering a perfectly dark room, you would naturally expect to see absolute darkness. If, however, you stay in the room until the eyes become accustomed to darkness, you will notice that the field before you is not absolutely black, but has the appearance of a faint misty haze or glow. This is called the intrinsic, or specific, light of the retina. By this intrinsic light of the retina we do not mean to say that there is actual light in the eye; it is a sensation of light, the cause of which is not well understood. Some have supposed that it is due to the bombardment of the sensitive portion of the retina by the blood-corpuscles referred to in Experiment 14. Others hold that it is not due to the retina, but to changes in that part of the brain where our visual sensations are produced.

It is a well-known fact that in certain diseased conditions, as in delirium tremens, the visual centers of the brain are abnormally stimulated, and the patient imagines he sees objects which have no objective existence.

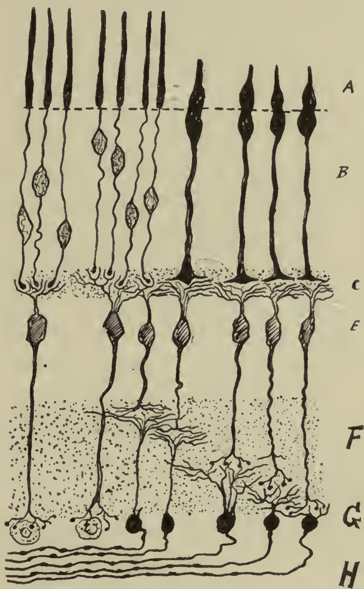

Fig. 27. Diagram of structure of the Retina (after Cajal). H, layer of nerve-fibres; G, layer of ganglion cells; F, internal molecular layer; E, internal nuclear layer; C, external molecular; B, external nuclear; A, layer of rods and cones.

The second requisite for distinct vision is the production of a change by the light in the eye of such a nature that it can be communicated to, or affect the endings of, the optic nerve in the eye. The sensitive element of the eye without which sight is impossible is the retina, the innermost coat of the eye (see Fig. 14). The retina has an exceedingly complex structure, but as our time is limited, we shall only refer to the most important points.

The optic or second cranial nerve is the nerve of sight, the impulses generated by the light in the eye are by means

of this nerve conveyed to the brain. This nerve arises from various structures, such as the geniculate bodies, optic thalamus, anterior corpus quadrigeminum, etc., found in the anterior portion of the brain. Soon after leaving the brain, the two optic nerves meet in the median line of the brain and after partial decussation (see Fig. 21) again separate and proceed to the eyes and end in the retina. But the endings of the fibers of the optic nerve in the retina come in contact (in layer F, Fig. 27) with the endings of another set of very short nerves. The other endings of these short nerves again come in contact with the endings of a third set of short nerves (in layer C, Fig. 27), whose external ends (upper ends in Fig. 27) have a peculiar structure, known as the rods and cones. Hence there are three sets of nerves in the retina. And it must be borne in mind that the fibers coming from the brain, and which are located in the layer of the retina designated H in Fig. 27, are innermost in the eye, while the layer of rods and cones (layer A, Fig. 27) is in the external part of the retina, that is, it is in contact with the choroid (see Fig. 14).

The question is, which part of this complicated mechanism is acted upon by light. In order not to burden you with too many details, we may say that the rods and cones are regarded as the ultimate elements of sight; they form the structures that the light acts upon in such a manner as to cause vision. Some of the reasons for this supposition are as follows. The portion of the retina where the optic nerve enters is known as the optic disk; it is also called the blind spot, because this part of the retina is absolutely blind (see Fig. 14).

Experiment 15. Close the left eye and with right eye look at the cross in Fig. 28; by indirect vision you will perceive the circle. Bring the page closer to the eye, all the time keeping your eye fixed on the cross. At a certain distance the circle will disappear. Bring the page still nearer and the circle will reappear.

This is known as Mariotte's experiment and is explained as follows. When we look directly at an object, the focus falls on the fovea centralis, or yellow spot (Fig. 14), and the images of other objects not in line with the first object fall outside of the yellow spot. When the page is held in the correct position, the image of the cross falls on the yellow spot and that of the circle on the blind spot. By microscopical examination it has been found that there are no rods or cones in the blind spot, hence this experiment is a strong proof in favor of the idea, that the rods and cones are the percipient elements. Right here I may draw your attention to something interesting. In the optic disk or

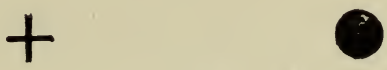

Fig. 28.

blind spot there is an abundance of nerve fibers for, as we have stated before, here the optic nerve enters. The light falls upon these optic nerve fibers and yet there is no sensation produced. We may conclude, therefore, that the nerve fibers themselves cannot be stimulated by light; the light must fall upon the endings of the nerves (rods and cones) in order that a sensation of light be produced. This is analogous to other sense organs. In order to have a sensation of touch the nerve endings in the skin must be stimulated, for if the skin is removed, touching the exposed nerve may give rise to a sensation of pain, but not of touch.

I may also state that Donders was able, by means of a small mirror, to throw a light on the blind spot, leaving the rest of the retina dark. In this case the person was not conscious of any sensation of light.

Another reason why we are certain that the rods and cones are the structures stimulated by light is as follows: As I told you, when we look directly at an object, the focus always falls on the fovea centralis, or yellow spot;

at this portion of the retina vision is keenest. Now this portion of the retina is also best supplied with rods and cones, especially the latter. As we proceed from the yellow spot to the periphery of the retina, vision becomes less and less distinct, and the number of rods and cones, especially cones, becomes also less and less.

That the rods and cones are the percipient elements of sight is further rendered evident by the fact that whenever they are destroyed, even if the other portions of the retina are intact, vision is gone. To these proofs we may still add the following, which is, I think, of interest.

Experiment 16. Look at the two points printed beneath.

••

These two points are seen as two distinct points. Move away from these points to a sufficient distance, and you will see only one point; the two points have fused and only one sensation is produced.

If the two points are further apart than here indicated, the distance between your eyes and the points must be greater in order to cause them to fuse. In other words, it is the angle under which these two points are seen that determines whether you see them as two points or as one point. The smallest visual angle under which two points are seen as two distinct points lies between 50 and 70 seconds. The following explanation is generally given for this phenomenon. In Fig. 29, N is the nodal point of the eye. By the nodal point* we mean a point in an optical system of such a nature that a ray of light going towards it before refraction, is not refracted in going through the optical system. In Fig. 29, let A and B represent the two points looked at. Each point sends a ray of light to the nodal point and these rays are focused on the retina at A′ and B′; hence, A′ is the image of A, and B′ is the image of B. If the angle included between the lines A N and B N is 73 seconds, the linear distance between the images A′ and B′ is about 5.36 micromillimeters, or .00536 millimeters; in

*In reality there are two nodal points, but as they lie close to gether, they may be regarded as one.

this case the points are seen separately. But suppose that the points are situated closer together, the angle A N B will be less than 73 seconds and the distance A′ B′ will be less than .00536 mm.; in this instance the two points are seen as one point. This is due to the fact that if two images fall on one rod or cone we have but one sensation, while if the two images fall on two rods or cones separated by a third cone, two distinct points are seen. In A and B of Fig. 30 the two images fall either on one cone or on two neighboring cones, and only one sensation is produced. In C, Fig. 30, two cones separated by a third cone are stimulated, and two sensations are produced. It was stated that the images (A′ and B′, Fig. 29) must be about .005 mm. apart in order to be perceived as two points. As the diameter of the cones is from .002 to .005 mm, these facts agree with the theory that the rods and cones are the ultimate elements of sight. It may be mentioned in passing that the determination of the visual actuity by the charts of Snellen, is based to some extent on this principle.

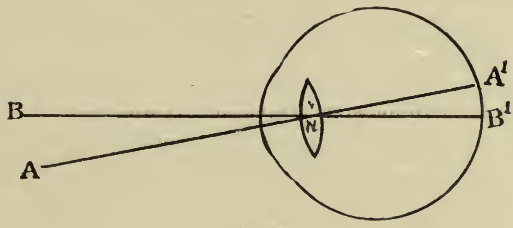

Fig. 29.

Having decided that it is the rods and cones which are stimulated by light, the next step is to determine what change is produced in the eye which enables us to see. There are quite a number of changes produced by the light in the eye. In the outer portions of the rods (see Fig. 27) is found a reddish pigment called rhodopsin, or visual purple. This pigment bleaches when exposed to light and in darkness it regains its colors. It behaves, therefore,

somewhat like a photographic plate, but is superior to it in that darkness restores the pigment. In fact, by means of this visual purple Kuhne was able to form a picture of an external object on the retina; such a picture is known as an optogram. Kuhne placed a frog in a dark room for an hour or two so as to increase the amount of visual purple. He then excised the eye and placed it in front of a window so that an image of the window with its panes and sashes fell upon the retina. After an exposure of some minutes he took the retina out of the eye and treated it with an alum solution, which "fixes" the rhodopsin so that it is no longer


A B C

Fig. 30. In these figures the two points correspond to the images a' and b' of fig. 29. In A they fall on one cone, in B on two neighboring cones; in both cases one sensation is produced and consequently one point perceived. In B the two images fall on two cones separated by a third cone and this causes two sensations and hence two distinct points are perceived.

affected by light. He then observed a picture of the window on the retina, in which the panes were colorless (bleached) and the sashes red.

When this action of visual purple was first discovered, it was thought that the riddle of how light produces its effect in the eye was solved. However, this fond illusion was soon dispelled, for it was found that visual purple is not necessary for vision, as is indicated by the following facts. There are some animals, like snakes and pigeons, that have no visual purple; as these animals can see perfectly well, it furnishes good grounds for supposing that it is not absolutely necessary for our vision. Again, if the human eye is exposed to the bright sky for ten or fifteen minutes all the rhodopsin is bleached, notwithstanding the eye is not blind. Visual purple is not affected by a red light, yet we are able to see red light. Besides this, the changes that rhodopsin undergoes when exposed to light are too slow to account

for vision; a flash of lightning is of too short a duration to affect this pigment.

There are many other changes produced in the eye, but none of them are absolutely essential to vision, so far as we know at present. Hence we are ignorant of the second requisite for vision, namely, a change produced by light in the eye. Nor are we better informed of the third requisite, the communication of this (unknown) change to the optic nerve and its propagation to the brain. We are certain that the light stimulates the endings of the optic nerve, and that this nerve conducts a nerve impulse to the brain which finally results in conscious vision; but what this nerve impulse consists of we cannot at present tell. Most likely it is no different from the nerve impulses going over other nerves in the body; the sensation of vision is not determined by any definite kind of stimulation or nerve impulse reaching the brain, but upon the definite place (center) in the brain where the nerve impulse causes a change in the cells of the brain. As we shall see later on, the visual sensations originate in the occipital lobes of the cerebral hemispheres of the brain. Here the optic nerves have their final endings. If these lobes are destroyed, psychical blindness results; if they are stimulated, we have the sensation of sight, no matter how this stimulation is brought about. This led someone to say that if the auditory or eighth cranial nerve which leads from the ear to that portion of the brain where auditory sensations originate, could be made to conduct impulses to the occipital lobes, we would be able to see the music played by a band.

Seeing that we are not acquainted with the nature of the change set up in the rods and cones and the impulse transmitted by the optic nerve, we shall leave this subject and next discuss the impressions that we receive when light falls into our eye. The retino-cerebral mechanism gives rise to three sensations: light, color, and space sensations. Certain animals possess organs which give them impressions of

light only. A differentiation of nerve fibers has taken place of such a nature that they are affected by light; but, as no lens is present, there are no images cast upon the nerve fibers, and all that these animals perceive is light. They can distinguish between light and darkness, but they have no idea of form or distance and most likely not of color.

In our discussion of the sensation of light, we may first inquire into the relation existing between the stimulus (the objective light) and the resulting sensation. How long must a light act and with what intensity must light act in order to be seen? It has been found that we can perceive a light lasting 1-8,000,000th of a second. We may, therefore, state that, so far as we know at present, if the light has a sufficient intensity, no matter how short its duration, it is visible. It must have a certain intensity for reasons which we will take up in our next lecture.

LECTURE V.

At the close of the last lecture we learned that the length of time required for the light to act upon the retina in order that it can be perceived is extremely short, a spark of light from a revolving mirror lasting only 1-8,000,000th of a second can be perceived. However, the sensation produced is not as short as this. The curved line in Fig. 31 represents the intensity of the visual sensation; the higher a certain part of the curve is above the base line (n m), the greater the intensity of the sensation at that moment. Let us suppose that the light which produced this sensation

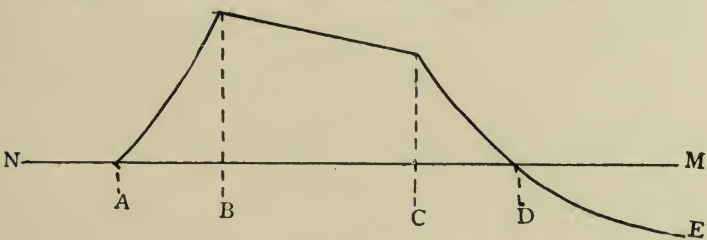

Fig. 31.

lasted from A to C. The curve of sensation can be readily divided into four parts: A B, B C, C D, and D E. At A the light begins to act upon the retina and the sensation begins; however, it will be noticed that the sensation does not reach its maximum immediately, but gradually increases in intensity until at B it attains its greatest intensity.

From this it is evident that a dim light acting for a longer length of time may produce a stronger sensation than a bright light acting for a very short length of time. Suppose an electric spark lasting but 1-1,000,000th part of a second falls upon the eye. In that length of time the

sensation has reached, let us say, only one-fourth the value that it would reach if the spark should last for one whole second. Let us now suppose that a second light having only one-half the brilliancy of the electric spark but lasting one second falls upon the eye. In that length of time the sensation has reached its full value which is, therefore, twice as great as that caused by the electric spark. You see that the eye is similar to a photographic camera in that the effect increases with the length of exposure; there is an accumulative effect.

This naturally leads us to ask, how much light must be thrown into the eye in order to produce a sensation? You will remember that irritability was defined as the power of a living being to respond to a stimulus. The smallest amount of a stimulus that can produce a sensation is called its liminal intensity. What is the liminal intensity of the light entering the eye? This is very difficult to state, for it is not an easy matter to measure and graduate the amount of light. For certain sense organs, such as touch, it is less difficult to determine the liminal intensity of the stimulus because one can readily measure the amount of pressure applied in milligrams or fractions of a milligram. However, attempts have been made to determine how great the luminosity must be in order to produce a sensation, and it was found that a sheet of white paper illuminated by a standard candle can still be perceived at a distance of 200 or 250 meters. If the distance is greater than this, it can no longer be perceived.

Moreover, the liminal intensity depends to a large extent upon the condition of the eye. It is a well-known fact that if your eye is accustomed to bright light, you do not readily perceive a very dim light, but after remaining in a dark room for some time, the dim light looks quite bright. In determining the liminal intensity of light, the retina should be in resting condition, in other words, it should be as sensitive as possible. Remaining in the dark for three min-

utes increases the irritability of the retina from ten to fifteen times, while after a stay of two hours the irritability is thirty-five times as great as when the eye is illuminated by daylight.

But even under these circumstances all eyes are not the same; sailors see land at a distance when a landsman cannot see anything. Artists and orientals have a much higher developed sense of color and light than other people. So the threshold of irritability or liminal intensity varies in different people and depends upon the condition of the eye and upon previous training. Neither is the threshold of irritability the same for all portions of the retina. In the last lecture we learned that when we wish to see an object distinctly, the focus of that object always falls on the fovea centralis, or yellow spot. From this you might infer that this portion of the retina is also the most sensitive to light, but the following experiment indicates that this is not true for light of all intensities.

Experiment 16. Turn the gas jet very low so that a mere spark of light remains and view this from a distance of about ten or fifteen feet. Close one eye and look directly at the gas jet; notice its luminosity. Now look a few inches to one side of the light, seeing this by indirect vision, that is, letting the focus fall outside of the yellow spot; the light appears very much brighter than it did before.

This experiment demonstrates that while in the ordinary sense the fovea centralis has the greatest visual acuity, the threshold of irritability is less for those portions of the retina immediately surrounding the fovea centralis than for the fovea itself. This has received the following explanation. As was stated in Lecture IV, the fovea centralis is well supplied with cones, but the rods (see Fig. 27) are lacking here. In the peripheral portions of the retina, that is, in the retina outside of the fovea, we find both rods and cones, the number of cones diminishing rapidly as we proceed toward the limits of the retina. Some physiologists

suppose that the rods and cones do not perform the same functions, and that the rods are color blind but are especially adapted for viewing light (not color) of low intensity. Some hold that this function of the rods is due to the rhodopsin or visual purple, which, as we stated in the previous lecture, is only found in the rods.

A subject closely related to this is known as the law of Weber, which states by how much a light must be increased in order that we maybe able to perceive the increase. As this law holds good within certain limits for other sensations, we may for a few minutes leave the subject of light. Suppose I draw a line of a certain length; how much longer must I draw a second line in order that the two may be distinguished? It has been found that if the first line is 100 mm. long, the length of the second line must be at least 105 mm. Again, if the first line is 200 mm., the second line must be 210 mm.; if the first line is 1,000 mm., the second line must be 1,050 mm. The difference between 100 and 105 is five, and the ratio of this difference to the length of the first line is 5-100, or 1-20. The difference between 1,000 and 1,050 is fifty, and here the ratio of the difference to 1,000 is 50-1,000, or again 1-20. Hence we may state this in the following general manner: In order that a difference in the length of two lines shall be perceived, the difference between the two lines must be a certain fraction (ratio) of the shortest line; this fraction is constant no matter what the length of the lines may be and its value is 1-20.

To a certain extent this also holds true for pressure sensations, as the following shows. If your hands rests on the table, and if a weight is placed on the hand, you experience a sensation of a certain strength. How large a weight must be added in order that you can perceive a change in the intensity of the sensation? It has been found that if the original weight is ten grams, one gram must be added to it in order that a change in the sensation can be per-

ceived. Instead of ten grams, the weight might have been ten grains, ten ounces, or any other weight; in each case 1-10 of the original weight must be added to produce a change in the sensation. If less than 1-10 is added, you are unable to tell the difference.† We may generalize this as follows: Whatever the strength of the stimulus may be, it must be increased by the same fraction in order that a difference in the sensation may be perceived. It will be noticed that this is the same conclusion that we arrived at in discussing the least perceptible difference in the lengths of two lines.

Does our sensation of sight follow the same law? It does. Suppose this room is lit by one hundred candles, how many candles must be added in order that we could perceive an increase in the luminosity? One candle must be added. That is, we can tell the difference between the light from one hundred and that from one hundred and one candles. The ratio of the difference to the original stimulus is 1-100, hence 1-100 is the ratio by which the light must be decreased or increased in order to cause a difference in the sensation. If instead of one hundred there are ten candles, then 1-100 of 10 or 1-10 of a candle must be added. Whether the light is furnished by candles, lamps, or electric lights does not alter the rule.

We may once more state this in general terms: The smallest change in the magnitude of the stimulus (light, pressure, etc.) which we can appreciate through a change in our sensation is always the same ratio of the total stimulus. This is called Weber's law.

Weber's law explains a great many phenomena that are familiar to you. We have time to call attention to but a few. A candle is burning in a dark room, and casts a shadow of an object on the floor. If a little daylight is let into the room, the shadow begins to fade away, and if

†This ratio differs for different regions of the body.

the bright sunlight falls upon the floor, the shadow cast by the candle disappears. The reason for this is as follows. In Fig. 32 let O be the object whose shadow falls upon the floor at P. This portion of the floor, therefore, receives no light, while the remainder of the floor, Q and Q, receives the full light of the candle, the intensity of which we shall call one. Now the full sunlight is let in which lights up the

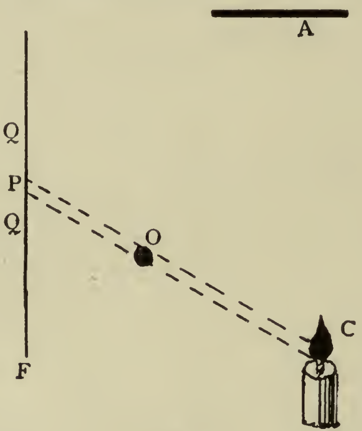

Fig. 32,

whole floor, the spot P as well as the neighboring portions, Q and Q. Let us call the intensity of the sunlight 1,000, that is, we shall assume that it is one thousand times as bright as the candle light. The portions of the floor Q and Q receive light both from the candle and from the sun, hence, the total luminosity of Q is 1,001. The place P receives light only from the sun, hence, its luminosity is only 1,000. The difference between the luminosity of P and Q is therefore 1, which is 1-1000 of the total luminosity of P. We have seen that two lights must differ by 1-100th part of the weakest light in order that we can perceive the difference. It is, therefore, obvious that the difference between the luminosity of P and Q cannot be perceived; the floor will have a uniform appearance.

We read a printed page by the light of a good lamp as well as in daylight, although the daylight is far more intense than the lamp-light. This also is according to Weber's law. Let us suppose that the intensity of the lamp-light is 10, that of daylight 1,000. In the lamp-light the amount of light that you receive from the white paper is ten (not taking into consideration the absorption of light) and the amount of light received from the black letters is, let us say, one. The ratio of the difference (9) to the total illumination (10) is 9-10; as this difference is greater than one-hundredth, you can read the letters. When you read in daylight, the amount of light from the white paper is one hundred times greater, that is, it is one thousand, but the light from the letters has also been increased by one hundred, that is, it is equal to 100. The ratio of the difference to the total illumination is 900-1000 or 9-10, the same as in lamp-light. Hence, you can see to read by a good lamp just as well as in perfect daylight.

Why do we not see the stars in the day time? Because the amount of light which they send is so small compared with the amount of sunlight, that the difference falls below the fraction of 1-100. If the light received from a star were 1-100 part of the light received from the sun, that star would be visible by day; but as no star sends this amount of light, we are able to see them only when the sunlight is decreased.

Weber's law holds good, however, only for certain intensities of light; in very feeble or very bright light other factors enter. Suppose you are reading by lamp-light and that the amount of light is gradually decreased, at first reading is still possible, for the reasons given above, but as the light becomes less and less, it becomes more and more difficult to distinguish the print, until finally it is impossible. The reason for this is that the intrinsic light of the eye (see Lecture IV) is added to both the light from the paper and that from the printed letter, raising the intensity of both

so that the difference is imperceptible. On the other hand, it is generally impossible to see sun spots with the naked eye, while these are visible if the eye is protected by smoked glass. This is not because the difference of luminosity between the sunspot and the surrounding surface of the sun is not sufficiently great for us to perceive it, but because the glare of the sun blinds the eye, which then no longer follows Weber's law.

In discussing the liminal intensity of light we spoke only of white light, but there is also a liminal intensity of colored light. In determining this it was found that if a very feeble light is cast upon a piece of colored paper, the light is colorless (gray). If the amount of light is increased, the proper color is perceived. Consequently in colors we have two thresholds; first, the absolute or light threshold, and, second, the chromatic or color threshold. All colors look gray in very dim light, for which the following reason has been ascribed. The small amount of light from a colored object has sufficient intensity to stimulate the rods, which, as we have seen a moment ago, have a lower threshold of irritability, but have no color vision; this intensity is not sufficient, however, to stimulate the cones, whose stimulation gives rise to color sensation. Hence the colored light of low intensity appears colorless.

When white light or mixed light falls upon the retina, the maximum effect of all the colors is not perceived at the same time. At the beginning of this lecture, we stated that the sensation does not reach its maximum immediately, but that the sensation increases gradually (see Fig. 31). Now the sensation of red light reaches its maximum sooner than that of green light; this gives rise to a curious color phenomenon, which can be demonstrated by means of the Benham spectrum top (Fig. 33). This consists of a disk, half white and half black. On the white surface are placed strips of black paper in concentric circles. If this disk is rotated on a wheel in the direction indicated by the arrow

(Fig. 33) the concentric bands give rise to color sensations which are from within outward, red, brown, olive, green, blue. If the wheel is turned in the opposite direction, the position of the colors is reversed.

A phenomenon somewhat similar to this is the "flicker" phenomenon. On a wheel rotate a disk half of which is white and the other half black. Cast a strong light upon it. If this is rotated with sufficient speed, a uniform gray is produced, which will be discussed in the next lecture.

Fig. 33. Disk of Benham.

But if the speed is decreased a flickering is produced, and a pattern of colors, red, blue, green, yellow, etc., is seen. By increasing or decreasing the speed, this pattern changes in a most surprising manner. No adequate explanation has yet been given for this curious phenomenon. It is not due to the decomposition or analysis of the white light, for it can also be observed in monochromatic light, that is, in light of one color.

Charpentier's Bands. We shall now rotate on the wheel a disk having three quadrants black and the remaining quadrant white. On rotating this slowly and keeping your line of vision fixed upon the center, you will notice a narrow

grayish sector, like a shadow, situated in the white quadrant, at the point A, Fig. 34. By looking attentively, it may be possible to locate a second band in the white sector (at B, Fig. 34). These bands are known as Charpentier's bands. It would lead us too far into the subject to attempt an explanation.

The last subject with which I shall trouble you in this lecture is irradiation.

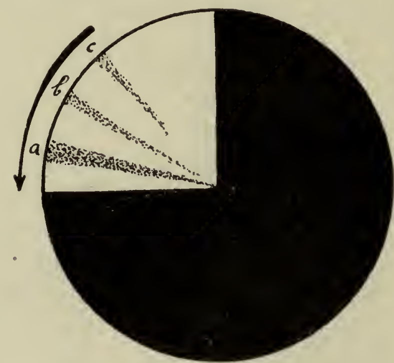

Fig. 34.

Experiment 17. Cut out two small squares of paper of exactly the same size, one of black and the other of white paper. Place the white square on a black background (on black cloth or paper) and the black square on a white background. The white square on the black background appears considerably larger than the black square on the white background. This is supposed to be due to a spreading of the sensation of white over the black, thereby enlarging the white square; but it is possible that spherical aberration also plays a part. The following experiment is also an illustration of irradiation.

Experiment 18. Hold the edge of a knife or card horizontally so that it shuts off half of the flame of a gas jet. Use a small flame. View the flame just over the edge of the card, and it appears as if the opaque object is notched at

the point where the object and the flame meet.

Two more illustrations of irradiation are the well-known facts, that people look smaller in dark than in white clothes, and that the darker old moon in the arms of the new appears smaller than the lighter strip of new moon encircling it.

LECTURE VI.

We have learned in the last lecture that the sensation produced by the stimulation of the retina does not reach its maximum immediately, but gradually increases in strength, till, after a certain length of time, it reaches its greatest intensity. This is graphically represented by the curve in Fig. 35. Suppose the stimulation by light lasted from A to C, the curve of sensation gradually increases from A to B.

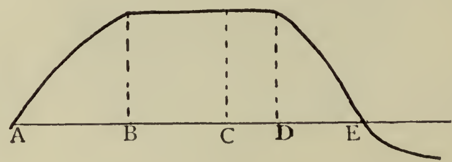

Fig. 35.

In this lecture we wish to consider the third part of the curve, that from C to D. As before stated, let us suppose that the stimulation ceases at C; it will be noticed that the curve of sensation does not immediately drop down to the base line. The sensation continues for a certain length of time, from C to D, gradually fading away; in other words, the sensation lasts longer than stimulation. If the stimulation (light) lasts for one second, the sensation produced by this stimulation lasts one second plus a fraction of a second.

We may, therefore, say there is an after effect, an after sensation. And this is true not only of our organs of sight, but also of other sense-organs. If a weight is placed on your hand, a sensation of pressure is experienced; if the

weight is removed, the sensation remains for a brief length of time.

The fact that the sensation lasts longer than the stimulation leads to the fusion of sensations. Since we were

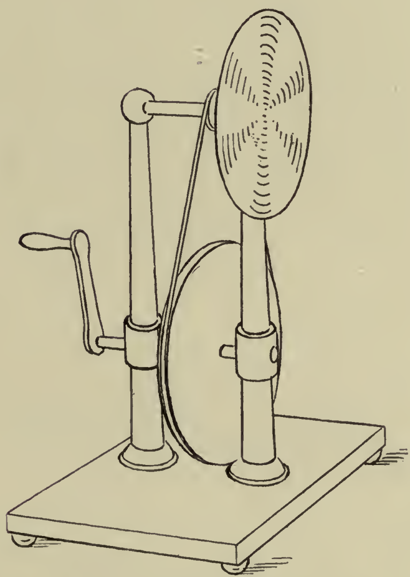

Fig. 36. Whirling machine for mixing colors.

boys, we were familiar with the fact that if a live coal is rapidly swung around, a circle of light is seen, especially if this is done in the dark. A similar phenomenon can be demonstrated on the color wheel (Figs. 36 and 36a).*

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*Nearly all the experiments related in this and in the following lecture were performed on the color wheel, an instrument by means of which disks of various colors can be rapidly rotated. Those desiring to follow these experiments at home, can procure from the Milton Bradley Co., Springfield, Mass., a simple "Color Top" with the necessary disks, which answers the purpose admirably. Not only can this "top" be used in making the experiments outlined in these lectures, but it will furnish very wholesome amusement to the children. The cost of top and disks is six cents, postpaid.

Experiment 19. On the spindle of the color top arrange a white and black disk, so that one-half of the field is white and the other half black. On rotating these disks slowly, you see the white and black sectors alternately and separately; but as the speed increases you notice that fusion takes place until finally there is no white or black, but a perfectly uniform gray.

This fusion of the two stimuli, white and black, depends upon the fact that the sensation lasts longer than the stimulation. Suppose Fig. 37 represents the retina and that the image of the white sector falls at A and that of the black sector at B. If the wheel is rotated slowly, the position of the image of the white area changes from A to B, and the

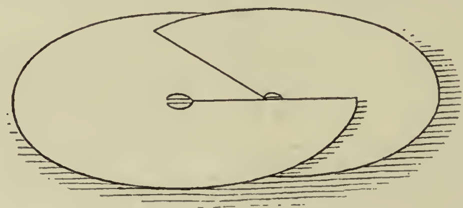

Fig. 36A. Color Discs

sensation at A disappears while a new sensation of the white area is formed at B. But rotate the wheel faster. The image of the white area leaves A, the stimulation of the white light ceases, but the sensation lasts, let us say 1-50 second longer. If the wheel is rotated so fast that the image of the white area is at A again before the expiration of the 1-50 second, then the second sensation fuses with the first sensation which remained, and consequently you are not conscious of that fact that the white area has changed its position; a uniform sensation is produced. This sensation is gray, because the black sector of the disk reduces the sensation of luminosity produced by the white disk.

This after-image, which outlasts the stimulation and upon which the fusion of the sensations depend, is called the positive after-image. How long is the duration of the posi-

tive after-image? This can be determined by ascertaining how often we must rotate the wheel in the above experiment in order to obtain complete fusion. We shall throw a dim light upon the wheel and rotate with sufficient rapidity to cause fusion. Now we will increase the light; you notice that I must rotate the wheel faster in order to cause fusion. This indicates that the number of stimulations per second must be very much greater in bright light than in dim light; the positive after-image lasts longer in dim light than in bright light. In dim light about thirteen stimulations per second are necessary; in the bright sun light sixty or more are needed.

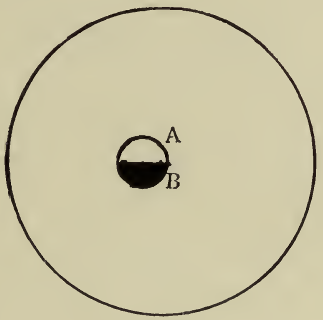

Fig. 37.

There is another form of positive after-image which is extremely interesting, which you can demonstrate for yourself, by the following experiment. As this experiment can be made only when the eye is in a perfectly fresh condition, it is best to make it immediately after waking. When you awake in the morning look out of the window for a short length of time, about five or six seconds; notice the trees and houses. Cover your face with the bed clothes and you will see a reproduction of the houses and trees. This after-image is so astonishingly perfect and clear that one can't help imagining that the eyes are open and still looking at the objects. This is also a positive after-image, but differs

from the ordinary positive after-image in its long duration. In the above experiment it is not sufficient to close the eyes, for a certain amount of light penetrates the eyelids.

You are all familiar with the positive after-image obtained by looking at the sun. If you look at the red setting sun, a very lasting after-image is seen which generally appears as a light luminous spot when the eyes are closed, while it appears as a dark circle when you look at a bright surface, as the sky. If you look steadily for some time at the setting sun, the after-image will be seen in colors which gradually change. At first the after-image is bluish green; this gives place to a green, and this in turn to a blue; then violet, pink, orange, and green are seen successively. What this change in color is due to, is not well understood. In some cases positive after-images have been known to exist for a life time; no doubt in these instances there is an actual injury to the retina caused by too strong stimulation.

The retina of our eye is stimulated by light, and consciousness is affected; but light is not the only agency that can thus stimulate the optic nerve. For instance, some people see stars, although there may be no light present. Mechanical stimulation of the optic nerve, as by cutting the nerve in operations for the removal of the eyeball, also produces a sensation of light. Passing an electric current through the eye also calls forth a sensation of light. Again, when the ear or the auditory nerve is stimulated, whether by sound waves, by a mechanical blow, or by an electric current, the result is always a sensation of sound. These facts have led physiologists to the theory of specific energy of nerves, by which we mean that the nature of the sensation (whether sound, sight, taste, etc.) is not determined by the nature of the stimulation applied to the particular nerve, but by the endings of that nerve in the brain. This is very well illustrated in people whose feet have been

amputated and who have subsequently complained of their painful corns. The nerve that originally supplied the toes is stimulated by the contracting healing tissue, and the result in consciousness is the same as if the corn was irritated.

Although the eye can be stimulated in these various ways, yet it is evident that the eye is not built for the reception of such stimuli. In fact, the organ of vision is constructed in such a manner that it can be best stimulated by light, i. e., ether vibrations; hence this form of stimulus is called the adequate stimulus. Other sense organs also have their adequate stimuli, that for the ear being the vibrations of air, or sound waves.

As ether vibrations are the adequate stimulus for the eye, it is necessary that we study them a little more closely. The lowest ether vibrations of which we have definite knowledge have 107,000,000,000,000 vibrations per second, and the shortest waves vibrate 40,000,000,000,000,000 times per second. However, all these vibrations of ether do not affect the eye. Our eye is stimulated only by vibrations ranging from 392,000,000,000,000 to 757,000,000,000,000 vibrations per second. If the number of vibrations is less than 390,000,000,000,000 or greater than 760,000,000,000,000 per second, they do not affect the eye, hence produce no sensation of vision (light). But these vibrations manifest themselves to us in other ways. If ether vibrations of, say 300,000,000,000,000 fall upon the skin, certain nerves are stimulated and we have a sensation of heat. The shorter wave lengths, i. e., waves having greater number of vibrations per second, have the power of changing certain pigments, as is seen in the bleaching of colors of cloth or paper; for this reason these short waves are sometimes called actinic, or chemical, rays. These short waves do not affect the human eye, but it is possible that other animals can perceive these vibrations. This is rendered very likely from what we know of other sense organs, such as the ear. Our ear can perceive sounds ranging from about 16 to 40,000 vibra-

tions per second. If a sound of more than 40,000 vibrations per second strikes the human ear, it causes no sound sensation, but a dog will respond to these sound waves. Lubbock states that ants and certain water beetles (Daphnia) seem to be able to see ultra-violet rays.

The rays of the sun which are visible to us have different rates of vibration, and according to the rate of vibration affect our eye differently. If the rate of vibration is 395,000,000,000,000 per second, the sensation called forth is red; if the rate is 740,000,000,000,000, we experience a sensation of violet. By means of a prism the white sunlight can be decomposed, i. e., the rays of various lengths can be separated from each other; the result is called the spectrum of the sunlight. The following table gives the number of vibrations and the wave length of the seven main colors seen in the solar spectrum:

	Number of vibrations per second.	Wave lengths in millimeters.*
Red	395,000,000,000,000	0.0007604
Orange	503,000,000,000,000	0.0005972
Yellow	517,000,000,000,000	0.0005808
Green	570,000,000,000,000	0.0005271
Cyan-blue	606,000,000,000,000	0.0004960
Indigo	635,000,000,000,000	0.0004732
Violet	740,000,000,000,000	0.0004059

In this table are noted only the seven chief colors which most people recognize in the rainbow. However, if you observe the spectrum carefully, you will notice that these seven colors gradually shade into each other, that there is no sharp line of demarkation between them, and that many more colors can be seen. Some state that at least 160 colors can be recognized. And if these colors are mixed in various ways, especially if they are mixed with white and with black, it is estimated by V. Kries that we can appreciate 500,000 different colors, tints, and shades.

*A millimeter is equal to about 1-25 (0.0393704) of an inch.

Colors have three distinguishing marks. First, we have the hue, or tone, of the color. By the tone of the color we mean what is ordinarily called the color, e. g., red, blue, green. Again, we can speak of the purity, or saturation, of a color aside from its tone, by which we mean the amount of white light there is mixed with the pure color.

Experiment 20. Take the red disk which is found in the outfit of the color top. Let us say that this is a perfectly saturated color, that is, its purity is one hundred per cent. On the color top combine 75 per cent red and 25 per cent white, and rotate fast enough to cause complete fusion. Although the resulting color is still red, the purity, or saturation, is decreased; the color is a light or pale red.

The more white light is mixed with the red, the less the saturation and the paler the color. Tints are produced by mixing a saturated color with white light; pink, for example, is a tint of red. It must be borne in mind, however, that a pure color is not necessarily a bright color, nor is a bright color necessarily a pure color. Some parts of the spectrum have so weak a tone that they can be recognized only with difficulty, yet they are pure colors.

The third color-constant is the intensity, or brightness, by which is meant the amount of light coming from a unit area of the colored object. In this connection we can speak of a "dark" red and a "bright" red; in both cases the saturation may be complete, but the bright red sends more red light into our eye than the dark red.

Experiment 21. On the color top combine 50 per cent red and 50 per cent black. On rotation, a very dark red is seen; this is called a shade of red. Instead of having the whole amount of red light from the red disk thrown on your retina, you only receive one-half of this amount and, consequently, the intensity, or brightness, is less. The last two experiments may be repeated with blue; in the one case a tint, in the other a shade of blue is obtained.

Speaking of the brightness or intensity of colors, leads us

to ask what is the brightest part of the spectrum. Most people agree that, with ordinary illumination, the yellow has the greatest luminosity. If, however, the intensity of the light is decreased, the brightest portion of the spectrum shifts over to the right, that is, into the green. On the other hand, if the intensity of the decomposed light is increased, the brightest part is found in the orange. This gives rise to what is known as Purkinje's phenomenon. While looking at a carpet or wall paper, the pattern of which contains red and blue colors, gradually decrease the light; the red colors gradually become darker and are indistinguishable from black, at a time when the blue can be readily discerned. When the intensity of the light is increased, the colors also become colorless, but the order in which they disappear is not the same as when the light is decreased.

We have seen that the white sunlight can be decomposed into its component colors, red, orange, yellow, etc. If we combine these colors in the proper proportion we again have white light. This can be done on the color top, but in all these demonstrations with the color top you must bear in mind that pure white is never obtained; instead of white, the result is gray, but gray is a white of less intensity.

Experiment 22. On the color top mix the following:

Red	12%
Orange	11%
Yellow	21%
Green	24%
Blue	18%
Violet	14%

A dark gray is obtained in Experiment 22, indicating that if these various colors are combined in the proper proportions, the effect is the same as we see them in the sunlight. However, to produce white light, it is not necessary to take all these colors. White light can be produced by the proper mixing of only two or three colors.

Experiment 23. On the color top mix:

Green	31%
Violet	34%
Red	35%
or	
Blue	25%
Green	31%
Red	44%

This experiment indicates that the sensation of white can be produced by the admixture of ether vibrations of various frequency. By mixing 50 per cent blue and 50 per cent yellow, a gray is also produced. Colors which on

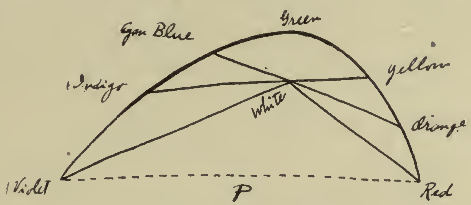

Fig. 38. Color triangle.

mixing produce white light are called complementary colors, sometimes also called contrast colors. The colors of the spectrum can be arranged in a diagram, as illustrated in Fig. 38. This is a triangle with rounded corners, at which are located red, green, and violet. Between them are the colors in the order in which they are found in the spectrum. Near the center of the triangle we have white. If you draw a straight line through the white, the colors that are located at the two ends of this line are complementary colors. For example, take the line which connects red and white; on prolonging this line, it cuts the triangle between green and blue. Here is located the bluish green of the spectrum, and this is the complementary color of red.

Experiment 24. On color top combine red 44 per cent, green 31 per cent, and blue 25 per cent; the result is gray

(white). Now mix green and blue in the same proportion as found in their combination with red, i. e., mix 44 per cent blue and 56 per cent green. This gives a bluish green which is complementary color of red.

In a similar manner it can be seen from the diagram that yellow and indigo are complementary. Again, orange and cyan blue (a greenish blue), and violet and greenish yellow form two pairs of complementary colors. In this manner we have found the complementary color of all the colors of the spectrum except green. If we draw a line from green through white, it cuts the broken line joining the red and violet. No spectral color is here located, but on this line is located a color not found in the spectrum. Can we determine what this color is? Yes; in the following way. If two colors, separated by a third color, are mixed, the result is the third color.

Experiment 25. With the large disks of the color top mix 9 per cent yellow and 91 per cent red, and with the small disks mix 37 per cent orange and 63 per cent black; rotate these simultaneously on the top. The result in both disks is a dark shade of orange.

Yellow and red are two colors separated in the spectrum by a third color, orange, and the mixing of these two colors produced this intermediate color. Now red and violet are separated by a third (unknown) color, to determine this color we need only mix red and violet.

Experiment 26. Combine 50 per cent red and 50 per cent violet. A beautiful purple is the result, a color which does not exist in the spectrum.

Experiment 27. As no purple papers are found in the color top outfit, we must, in its stead, use those colors that by their mixing produce purple, viz., red and violet. On wheel mix 31 per cent green, 34 per cent violet, and 35 per cent red. The result is a gray (white), proving that purple and green are complementary colors.

LECTURE VII.

In our last lecture we discussed color mixing with special reference to complementary colors. We showed that by the proper mixing of two or three colors, white light can be produced; such colors are called complementary colors. In this lecture we shall continue the subject of color mixing and state one or two theories which seek to explain these results.

It can readily be demonstrated that it is possible to produce white light and all the colors found in the spectrum by the proper mixture of only three colors. These three colors are called the primary, or fundamental, colors. The selection of these three colors is somewhat arbitrary, but generally red, green, and violet are taken. By the proper mixing of these primary colors any color and white can be produced, as we shall prove by the following experiments. It will be remembered that the spectrum is divided, broadly speaking, in the seven main colors: Red, orange, yellow, green, blue, indigo, and violet. Of these we are able to produce orange, yellow, blue, and indigo by the proper mixing of the primary colors.

Experiment 28. On the color-top combine 28% green and 72% red. A shade of yellow corresponding quite closely to yellow shade No. 2* is produced. Now with the large disks mix 16% green and 84% red and with the small disk 25% orange and 75% black; rotate these simultaneously on the color-top; a dark shade of orange is produced by both disks. By mixing 26% green and 74% violet, a light blue is obtained.

* The Milton Bradley Co., Springfield, Mass., issue a small book of sample colors (paper). The colors, shades, and tints referred to in this lecture are taken from this booklet.

In this experiment we have formed yellow, orange, and blue from the three primary colors. In the same way we can form the intermediate colors. We may say in general that every color sensation and white and gray can be produced by the proper mixing of other color sensations; in fact, certain color sensations, e. g., purple, can be produced only by the mixing of other color sensations.

Many theories have been advanced to explain color vision. The Helmholtz theory states there are three fibres

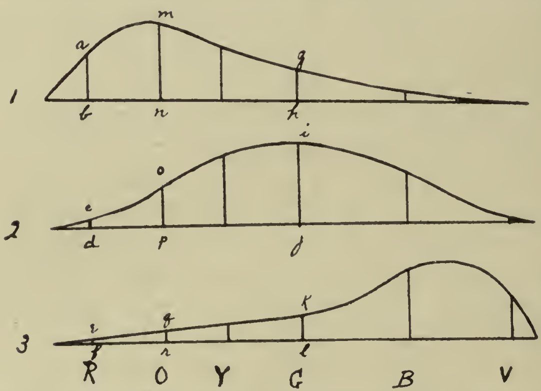

Fig. 39. Diagram of the three color sensations.—Helmholtz.

(or substances) in the eye; a red fibre, a green fibre, and a violet fibre (Fig. 39). The red fibre (upper curve of Fig. 39) is stimulated very strongly by the red light, to a slight extent by the green, and very slightly by the violet. The green fibre is slightly stimulated by both red and violet, but to a much greater extent by green light. The violet fibre is stimulated most strongly by the violet light, less by the green light, and least of all by the red light.

It will be noticed that all three fibres are acted upon by all three of the primary colors. How are the various color sensations produced? The sensation of red is produced when the red, the green, and the violet fibres are stimulated to the relative extent of ab, cd, and ef respectively (Fig.

39). In a similar manner it is evident from Fig. 39 that a sensation of green originates by the simultaneous stimulation of the red, green, and violet fibres to the extent of gh, ij, and kl respectively. How does this theory explain the perception of colors other than the primary colors? How, for example, is the sensation of orange produced? Orange is produced by the stimulation of the red fibre to the extent of mn, by the stimulation of the green fibre to the extent of op, and by the stimulation of the violet to the extent of qr; the last quantity is so small that for all practical purposes we may neglect it. Now experiment 28 has shown us that by mixing 16% green plus 84% red, a dark orange is obtained. This is, therefore, in harmony with the Helmholtz theory. Again, from Fig. 39, it can be seen that to produce the sensation of yellow, red and green must again be mixed (neglecting the small amount of violet), but that the amount of green must be greater while the amount of red must be less than that needed for the production of orange. Experiment 28 demonstrated that this is correct, for to produce yellow we used 28% green plus 72% red. Again, Fig. 39 indicates that blue ought to be produced by the stimulation of the green and violet fibres (neglecting the small amount of red). Here again experiment 28 agrees with the Helmholtz theory. According to this theory, if all three fibres are stimulated to the same extent, the sensation is white; experiment 23 has shown us that by mixing violet, red, and green, a gray is obtained. Hence the Helmholtz theory is true here also.

Another theory of color sensation is known as Hering's theory. The Hering theory of color sensation postulates the existence of three substances in the eye, a red-green, a yellow-blue, and a white-black substance. When light falls upon the retina, these substances are broken down or built up in the following manner. Red light decomposes the red-green substance, while green light builds it up; yellow light causes the breaking down of the yellow-blue substance, and

blue light causes it to be built up. All light, no matter of what color, causes decomposition of the white-black substance, this substance being regenerated in the absence of light. Complementary colors are explained by this theory in the following manner: Yellow and blue, as we have seen, are complementary; if mixed, white is produced. The yellow light causes decomposition, the blue light causes building up of the yellow-blue substance. If the destructive and constructive processes are equal, the yellow-blue substance undergoes no change, and consequently no color is perceived. But both yellow light and blue light cause decomposition of the white-black substance, and this produces the sensation of white. Hence the proper mixture of yellow and blue causes the sensation of white.

Thus far we have discussed the combination of complementary colors; what happens if colors are mixed that are not complementary? This may be answered by the following experiments.

Experiment 29. On the color-top mix green and blue in various proportions. It will be noticed that the resulting sensation is either a greenish blue or a bluish green; no other color sensation can be produced. Blue and green are neighboring colors in the spectrum (Fig. 38), and the colors originated by their mixing always lie between these two colors, and are found as such in the spectrum. The same can be demonstrated by combining yellow and green in various proportions.

Suppose the colors lie further apart, what is the result? Experiment 25 has taught us that if two colors, separated by a third color, are combined in the correct proportion, the intermediate color is produced. For example, red and yellow (separated by orange) on mixing produce orange. Again, suppose the colors are still further apart. In general we may state that if the two combining colors are situated closer together than their complementary colors, the resulting color lies between the two colors that are com-

bined, but if they are situated further than the complementary colors, the resulting color lies outside of the complementary colors and resembles more or less a purple.

Experiment 30. Combine green and red in various proportions; the result is a yellow or orange. The complementary color of red is bluish-green; hence the two colors mixed in this experiment lie closer together than the complementary colors (see Fig. 38), and the result is an intermediate color, either yellow or orange. The same can be proved by combining violet and green, which are closer together than the complementary colors (violet and greenish yellow). The result is a greenish blue, a bluish green, a blue, or a bluish violet, depending on the proportion of green and violet combined.

Experiment 31. Combine red and blue in the following proportion:

a. 50% blue plus 50% red equals violet.

b. 25% blue plus 75% red equals purple.

The two colors here combined are further apart than the complementary colors (red and bluish green) and the resulting colors, violet or purple, lie outside of the complementary colors (compare Fig. 38). The same can be demonstrated by combining 43% violet plus 57% orange, which gives a very beautiful red (tint No. 2); this lies outside of the complementary colors (violet and greenish yellow).

If two color sensations are identical and both of them are altered to the same extent, the resulting sensations are again identical. This is strikingly brought out in the following experiment:

Experiment 32. With large disks mix 16% green and 84% red, and with smaller disks, 25% orange plus 75% black. In both disks a dark orange is seen. Now introduce 20% violet in both the larger and smaller disks. In order to keep the proportions true, it is evident that the amounts of the red and green in the larger and of the

orange and black in the smaller disk must be decreased. The following gives the correct proportions:

Larger disk:—20% violet plus 12½% green plus 67½% red.

Smaller disk:—20% violet plus 20% orange plus 60% black.

Place these two disks on the color top and the sensations produced by them are identical—a dark red, nearly identical with the "A-Red dark" of the broken spectrum scale.

The foregoing experiment demonstrates clearly that if two equal sensations are produced by two different physical stimuli, altering both stimuli equally, also alters the sensations equally, and hence the sensations remain equal. Before we dismiss the subject of color mixing, I may be permitted to state one more interesting, although somewhat complicated, experiment.

Experiment 33. Combine—

A. 20% orange plus 80% blue equals violet.

B. 50% red plus 50% violet equals purple.

In equation B, instead of using 50% violet we can use the value of violet found in equation A, that is, 20% orange plus 80% blue. The equation then becomes:—

C. 50% red plus 10% orange plus 40% blue equals purple.

Place this on the small disk, while on the large disk you have B. Both C and B produce the same purple. Again, red can be produced by mixing:—

D. 36% blue plus 64% orange equals red (tint No. 2).

We can substitute this value of red in equation C and obtain (by taking one-half of the blue and of the orange of D):—

E. 18% blue plus 32% orange plus 10% orange plus 40% blue equals purple.

Simplifying this by combining like factors we have:—

F. 58% blue plus 42% orange equals purple (called violet red, tint No. 2, in Bradley's Color book.)

If now B and F are rotated simultaneously on the color top the two resulting colors are nearly identical.*

There is still one point to which I must call attention, because it will remove certain objections that may be raised in some minds against the theory of color mixing as here outlined. I refer to the mixing of pigments. It is well known to artists that the mixing of blue and yellow paint produces green. Yet we have called these colors complementary colors, that is, by their mixture they produce white. This difference can readily be explained; but before proceeding to this, let me make the following observation. When we combine colors on the color top we do not combine colors, but color sensations. In fact, colors have no objective existence; colors are psychological phenomena. What corresponds to colors are ether vibrations of different lengths. For example, when we view the yellow in the spectrum, the eye is stimulated by ether waves having a length of 0.00058 mm.; when we view the blue, the eye receives ether waves having 0.00047 mm. length. We can let these two waves fall into the eye simultaneously and the result is a sensation of white. It must not be imagined that the waves of 0.00047 mm. and 0.00050 mm. length have combined or fused; what has been combined is the sensation of yellow and the sensation of blue, and this results in an entirely new sensation, viz. white. To explain this combining of sensations, theories of color vision, such as the Helmholtz or the Hering theory, are put forward.

This happens when two colors are simultaneously thrown into the eye, as is done by means of the color wheel. What happens when yellow and blue pigments are mixed? Yellow pigment is yellow because it absorbs all the light rays ex-

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*B and F are not absolutely identical. The sensation of B is equivalent to that called violet red in the Bradley's color booklet; while F. as above stated is equivalent to violet red tint No. 2. This is due to the fact that in D the blue and orange did not produce saturated red, but red tint No. 2. If it were possible by these disks to produce a saturated red, the result in B and F would be identical. I would suggest that if a color wheel with disks in three sizes is accessible the experimenter compare B, C and F, by rotating them simultaneously. The result is very striking.

cept the yellow and some of the green, it reflects these into the eye. Blue pigment, on the other hand, absorbs all except the blue and some of the green; hence when the two are combined, the yellow pigment absorbs the blue reflected by the blue pigment, the blue pigment absorbs the yellow reflected by the yellow pigment, but both reflect the green. Consequently by mixing them there is no combining of color sensations in the eye or brain, but there is an elimination of ether waves.

After this lengthy discussion of color mixing we shall proceed with the subject of color-blindness. Color-blindness is the inability to discriminate between certain colors which the normal eye finds no difficulty in distinguishing. The number of color-blind people is stated at about three or four per cent in the male and one-fourth of one per cent in the female. Color-blindness may be inherited; the daughter of a color-blind person may have normal color vision, but have sons who inherit the grandfather's defect. Strange as it may appear, color-blindness may be monocular, *i. e.*, may exist in one eye only, the other eye having normal color vision. As in one form of color-blindness green and red are confused, it is of the greatest importance that employes of railways and steamboats be carefully examined as to their color vision, seeing that red and green signals are used to indicate safety or danger, etc.

One form of color-blindness, which is very rare, is achromotopsia, in which no colors whatever are perceived; only white, black, and the various shades of gray are seen. To such people a painting appears as an engraving. The most common form of color-blindness is red-green blindness in which, as already stated, red and green are confused. Some hold there are two classes of red-green blindness, the red-blind and the green-blind; others say there is but one class, but that the color vision varies somewhat in different color-blind individuals. We have not the time to enter into the details of color-blindness and shall very briefly state

the most important points. The red-blind mix up light red with dark green; to the green-blind light green and dark red appear identical. The red part of the spectrum is invisible to the red-blind, while the green-blind is said to see the spectrum in its normal length. To both the red-blind and green-blind the yellow and the blue are said to be normal. In fact, all the colors which they are able to perceive can be produced by the proper mixing of two colors, yellow and blue. It will be remembered that for the normal individual all colors can be produced by mixing three colors, viz., red, green, and blue (or violet). Hence, the normal color vision is said to be trichromatic, while the vision of the red-green blind is dichromatic.

The method which is now generally employed to detect red-green blindness is the "Holmgren method." In the Holmgren method a pile of worsteds of various colors, shades and tints is used; the examinee is given a "test-skein" which must be matched by tints and shades of the same color selected from the pile of worsteds. The first test-skein given to him is a light green. If his color vision is normal he matches this only by green of various tints and shades. If he is red-green blind, he selects besides the greens, pink, yellow, orange, red-grays, and pure grays. He is then handed a pale rose test-skein. The red-blind chooses blue and violet, while the green-blind selects gray and green. Finally a bright red test-skein is given; the red-blind selects, in addition to the red, green, and browns of a darker shade than the test-skein, while the green-blind selects light greens and light browns.

As there are various degrees of color blindness, a person may fail on the first test and pass the second and third tests successfully; he is then said to be incompletely color-blind. Some people have no difficulty in distinguishing between red and green if the colors are viewed in full light or at close range, while they fail to recognize them when the

colors are placed in unfavorable condition, such as great distances, dim light, etc.

Dalton, the great chemist, was red-green blind; he was unable to find his scarlet coat on the green grass. As he was one of the first to describe this defect, red-green blindness is sometimes called Daltonism.

Another form of dichromatism is the yellow-blue blindness, in which all the colors can be obtained by mixing the two colors red and green. Yellow and blue are confused with green or red. This form is much rarer than the red-green blindness.

Various explanations have been given for color-blindness, depending on the various theories of color vision. In general we may say that there is a lack of the color perceiving element in the eye or brain. That the defect is perhaps located in the eye is proved by the fact that one eye may be color-blind while the other eye is normal, and that by heating the eyeball of a color-blind person the defect disappears temporarily.

Color-blindness may be brought about by disease, such as disease of the optic nerve, and by the abuse of tobacco and certain other substances. In epilepsy there may be intermittent color-blindness. As I said a little while ago, the percentage of color-blindness is much higher in men than in women. Perhaps this is due to the better training in colors that girls receive; if this is true, it may be possible to reduce the per cent of the color-blind by properly educating our children. It is claimed that color-blindness is more prevalent among savages than civilized people. Recent investigations in Patagonia have proved that very many of the savages have no color sensations of blue; blue and black appear identical. From the study of the color terminology of Homer, Gladstone concluded that the old Greeks were color-blind. It would seem, therefore, that the color sense is a recent acquirement of the human race, and this is borne out by the development of the human being, a

child is unable to distinguish colors till toward the end of the second year. However, as many lower animals give indisputable evidence of color sense, it does not seem likely that this faculty should be lacking in primitive man.*

Certain portions of our retina are always color-blind. The fovea centralis may have normal color vision, but the

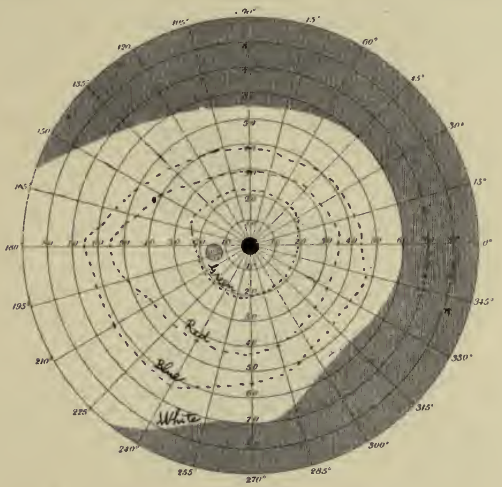

Fig. 40. Perimetric chart of the left retina, showing the extent of the retina on which the various colors can be perceived. The shaded circle a little to the left of the center is this blind spot,

farther we proceed to the periphery of the retina, the less the color sense, and at the extreme border of the retina we have no color sense whatever. Fig. 30 is a map of the left retina, indicating the extent of the retina by which the various colors can be perceived. It will be noticed that the field for green is extremely limited, while that for blue is the greatest, and that the outer portions of the retina are absolutely color-blind.

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* See the interesting article on Primitive Color Vision, by Dr W. H. R. Rivers, in the Popular Science Monthly, May, 1901. Vol. LIX page 44.

Having discussed color sensation and the theories of color vision, we are now ready to proceed to the subject of negative after-images, or successive contrast.

Experiment 34. Look intently for one or two minutes at the cross in Fig. 41. Next fix your gaze on a small mark on a white sheet of paper. A negative image of Fig. 41 is seen in which the upper left and lower right hand quarters are black, while the other two quarters are white, hence the reverse of the original figure.

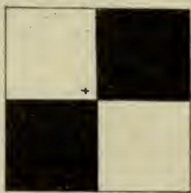


Fig. 41.

This after-image is called the negative after-image because in it the light and dark and also the colors are the reverse (negative) of the original (positive); it is sometimes called successive contrast, because it is a contrast which succeeds, or follows, the original image.

Experiment 35. Upon a white sheet of paper place a red piece of paper or cloth and fix your eye upon a certain spot of the colored object. It is very necessary not to shift the line of fixation. After one or two minutes look at a uniform white surface and a bluish green negative after-image is seen. Try the same with green, yellow, and blue objects.

From this experiment it is evident that the image of a colored object is followed by a negative after-image in which the original colors are seen in the complementary colors.

The explanation of the formation of the negative after-image that we shall give is based on the Hering theory of

color vision. At the beginning of this lecture we stated that Hering postulated the existence of three visual substances in the retino-cerebral mechanism, the red-green, the yellow-blue, and the white-black substances. Suppose the eye is exposed to yellow light; great destruction of the yellow-blue substance takes place. The red-green substance is not affected and the white-black is broken down to a small extent. This last effect we need not consider at present. After the yellow-blue substance has been broken

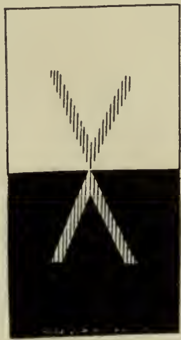


Fig. 42.

down to a considerable extent, white light is thrown into the eye. The red and green of the white light cause simultaneous and equal construction and destruction of the red-green substance, and therefore produce no color sensation. The yellow light in the white light normally causes destruction of the yellow-blue substance, but as this substance has previously undergone great destruction, the breaking down, when white light is looked at, is extremely limited. On the other hand, the blue light, which always causes the building up of the yellow-blue substance, now finds plenty of material to build up; hence the white light does not appear colorless but, owing to the great regeneration of the yellow-blue substance, appears blue.

This is the negative after-image of yellow. In a similar manner all the negative after-images obtained in experiment 35 can be explained.

In passing we might mention that Helmholtz explained the origin of negative after-images as due to fatigue. This is not correct, for these images are best seen in the morning when the eye is least susceptible to fatigue. Young and vigorous persons see these negative after-images better than old and feeble people.

Negative after-images can also be obtained by exposing the eye to an object (like Fig. 41) and then closing the eye. Perhaps this is due to the intrinsic light of the eye

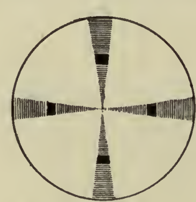


Fig. 43

which we have mentioned before. We might ask the question, are the negative after-images due to processes taking place in the brain or in the eye? This cannot be answered satisfactorily. It is true, as one can prove by experiment, that a sudden change in the accommodation of the eye, or a sudden movement of the eyeball, causes the image to disappear. If the eyeball is mechanically displaced, as by pushing it with the finger, the negative after-image also moves. These facts indicate that the development of the negative after-image depends on changes occuring in the eye itself; however, the question is not settled. The following experiment is also due to negative after-images.

Experiment 36. With the right eye look at a red object (paper, cloth) for one or two minutes; on now looking at a violet color, this appears blue, as can be seen by quickly

closing the right eye and opening the left eye. If the eye is first exposed to yellow light, orange appears reddish-orange. Yellow has a greenish yellow appearance if the eye is previously stimulated by orange light.

There is another contrast which is called simultaneous contrast because it occurs simultaneously with the viewing of the complementary color.

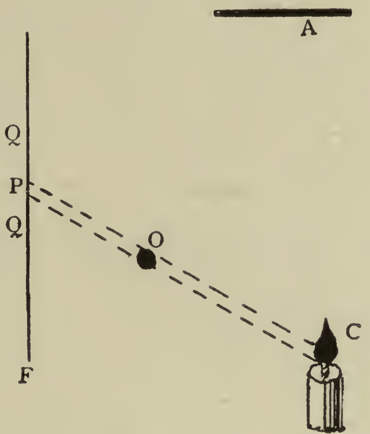


Fig. 44

Experiment 37. On viewing the gray V-shaped figures in Fig. 42, the V on the black field appears lighter than the gray on the white field, although both have the same intensity. This is due to contrast.

Experiment 38. On a white and on a black field as shown in Fig. 42 place small squares of red, yellow, green, and blue paper. The colors on the black field are considerably brighter than those on the white field. A color in a dark setting appears brighter and livelier than in a bright setting.

Experiment 39. On a piece of yellow paper paste narrow strips of gray paper (about 1-12 or 1-8 inch wide). On covering the whole by a piece of white tissue paper, the gray strips appear bluish. If gray strips are placed on green paper, the strips look reddish. The color of the background induces the complementary color in the gray. This is also shown in

Experiment 40. On a color wheel rotate a disk such as represented in Fig. 43. The disk is made of white paper, the shaded sectors are made of colored paper and the black squares in the colored sectors are pieces of black paper. Suppose that the colored paper is red; on rotating, the ring occupied by the black squares is not gray as one would expect, but it appears in the complementary color, greenish blue. Whatever color may be used, the ring is always seen in the complementary color. We may state that this experiment does not succeed very well in artificial light.

One more experiment before I close this lecture.

Experiment 41. On the table place a sheet of white paper (F in Fig. 44) illuminated by feeble daylight (from the window A, Fig. 44). Have a lighted candle or a lamp, C, in such a position that the shadow, P, of an object, O (a lead pencil, for example), is cast on the paper. Regulate the amount of daylight falling on the paper so that the shadow P is dim; it appears bluish. This is because the lamplight is not white but yellow. The light from the paper illuminated by the candle is yellow, that is, Q and Q in Fig. 44 are yellow. The light received from the shadow is white but the neighboring yellow induces a blue color. This experiment can be varied by using colored glass, red or green, so that the field is illuminated not only by the white daylight but also by the colored light. The shadows will be seen in the complementary colors.

These experiments on simultaneous contrast indicate that the sensation resulting from the stimulation of a cer-

tain portion of the retina depends not only upon the nature of the stimulation but also upon the condition of neighboring parts of the retina. To use the phraseology of Hering's theory, if destruction of the yellow-blue substance takes place in a certain portion of the retina (whereby the sensation of yellow is obtained), in the adjoining part of the retina the opposite process, that is, the building up of the yellow-blue substance, may occur and the resulting sensation is blue.

LECTURE VIII.

At the beginning of the second lecture we stated that the fourth requisite for vision is the projection of the sensation into space. This subject will occupy us in our last lecture.

As we stated in the first lecture, the images on the retina are inverted. Yet we interpret these images correctly, that is, we "re-invert" them so that we see the object in its correct position. How this is accomplished is difficult to say. We are ordinarily not conscious of the so-called special sense organs, like the ear and eye, when they are stimulated, but always refer or project the sensation produced by their stimulation into the outer world. This is not true for all our sensations. When, for example, a knife cuts through the skin, we do not think of the knife but of the seat of the pain; in other words, we project the sensation of pain to a certain part of our own body and not to the outer world. To a certain extent this is also true for the sensations of heat and cold. If our feet rest upon a cold piece of iron, we generally project the sensation into the outer world and are conscious of a cold object; we think of the cold as residing in the foreign object, if I may use this expression. But when a gentle stream of cold air comes in contact with our feet, we seldom think of the cold air but we say our feet are cold.

Our visual sensations are always projected into space, even when the cause of the stimulation resides in the eye itself, as is seen in the intrinsic light of the retina. This projection is not at hap-hazard, but follows a definite law so that our hand, guided by our visual sensation, can be laid upon the object seen. The law of this projection is that we project the sensation into the outer world along

the line which joins the image formed on the retina with the nodal point of the eye. Of the many examples proving this, we have time to call attention to only one or two.

Experiment 42. Press the outer corner of the right eye with the tip of the finger. A phosphene is seen (see experiment 12) and it will be noticed that this phosphene is situated to the left. Suppose, in Fig. 45, the finger is applied to the eye at a. This portion of the retina is mechanically stimulated and a sensation is produced. The nodal point of the eye is at n; the sensation produced by the stimulation at a is projected in the direction of the line anx and hence the phosphene appears on the side opposite to the point of stimulation.

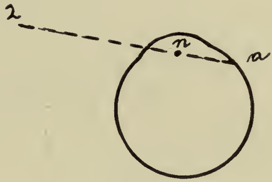


Fig. 45

Another proof of this law is seen in—

Experiment 43. Close the left eye and with the other eye look at an object. Suddenly place a prism before the eye in such a manner that the base (thickest part of the prism) is toward the right. The object now appears displaced, as can readily be seen by turning the prism slowly around a horizontal axis. When the base of the prism is to the right (temporal side), the object seems to be located more to the left of the experimenter; when the base of the prism is held toward the nose, the object appears to be situated on the temporal side.

The reason for this is as follows: In Fig. 46 let a be the object looked at with the right eye. The object sends one ray of light through the nodal point (n), this ray is not refracted (broken line in Fig. 46) and the image of the

object lies where this line meets the retina (at b). The sensation produced is referred from b through n to the outer world. Now place the prism in front of the eye so that its base is toward the right (temporal side); the ray of light in passing through the prism is refracted toward the base of the prism so that it now strikes the cornea at c, and after refraction in the eye stimulates the retina at d. The sensation produced at d is projected through the nodal point (n), hence the object appears to be situated at a'. If the

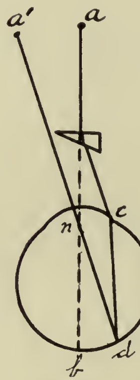


Fig. 46

Fig. 47

base of the prism is placed to the left, the object appears to be displaced to the right.

It is for this reason that the pin in experiment 6 appears to move in a direction contrary to its actual movement. It must be borne in mind that in experiment 6 we do not see the image of the pin, but its shadow; this shadow is not inverted (as the image always is), but in projecting it into space we invert it and therefore the sensation as interpreted by us does not correspond with the actual condition of things.

Although we have two eyes and therefore have two separate images, yet we have but one sensation. The explana-

tion generally given for this phenomenon is the theory of corresponding or identical points.* Suppose L and R in Fig. 47 are the left and the right retina respectively, and let us suppose that y and y^1 are the yellow spots. These two points are identical. Again, the points a and a^1 are situated in the same direction and at the same distance from the yellow spots and are also identical. The points a and b are not identical. It is held that if the images of a single object fall on identical and corresponding points we have one sensation; but if an object has its images on two non-corresponding points of the retinas, this object is seen double (diplopia).

Experiment 44. Hold a pencil about eight inches from the face and another pencil as far away as possible. Look at the further pencil and the nearer pencil is seen double. It may at first be difficult to see this; the following will aid you in making the experiment. While looking at the far pencil, shut the right eye and the near pencil appears to be situated to the right of the far pencil. Now look at the far pencil with the right eye and the near pencil is situated to the left of the far pencil. Knowing where the near pencil appears to be situated, look at the far one with both eyes and I think you will have no difficulty to see the near pencil double. The reason why this is double and why it seems to be situated to the right when viewed with the left eye can be gathered from Fig. 48.

Let the far pencil be situated at A and the near one at B. The pencil A sends a ray of light through the nodal point (n) of the left eye, L, and another ray through the nodal point of the right eye, R. These rays are not refracted, and as we are looking directly at A, the images of A fall on the yellow spots, y and y^1, of L and R. The yellow spots are

*Identical or corresponding points of the two retinas are points of such a nature that if they are simultaneously stimulated by the images of one and the same object, a single sensation is produced. It is interesting to note that this theory was already held by Alhazen, an Arabian mathematician of the eleventh century.

identical points and A is therefore seen single. B, the near pencil, also sends rays through the nodal points which are focused at o and o[1]. These are non-corresponding points, because they lie on opposite sides of the yellow spots (see also Fig. 47), and hence we see this pencil double. As we stated a few moments ago, we project the sensation into space along the line which joins the stimulated point of the

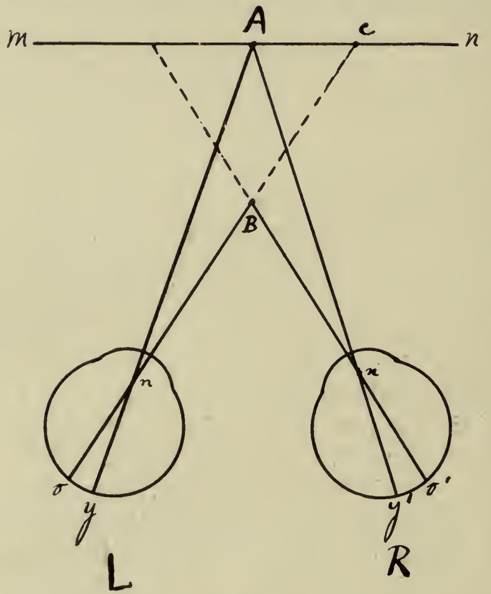


Fig. 48

retina (b in L, Fig. 48) with the nodal point (n); hence the near pencil is seen with the left eye along the line bnc. In projecting our retinal images, we always project them to the plane for which the eye is focused; that is, in Fig. 48, to the plane mn in which A is situated.

In Fig. 49 the eyes are focussed for the near pencil B and the far pencil A is seen double, because the images of A fall at o and o[1] which are not identical points. When these images are projected to the plane for which the eyes are

focussed (mn), it will be noticed that the projected image for the left eye lies to the left of B, differing, therefore, from the previous experiment.

In this place I may draw your attention to another interesting fact. When a person is asked to hold his finger in line with a distant object, he always holds it in the line which joins the object with the right eye. If he closes his

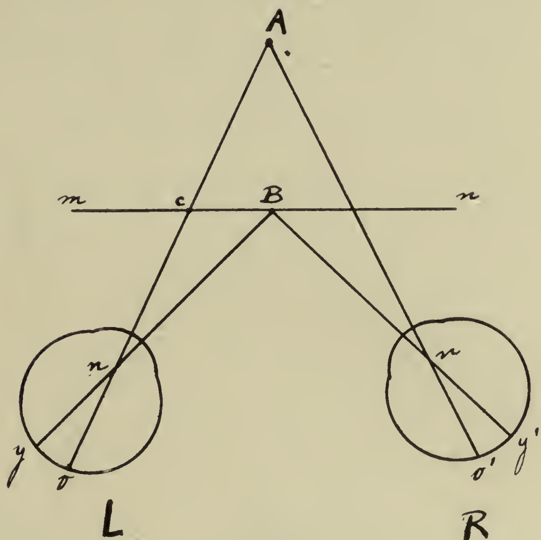


Fig. 49

right eye, the finger is no longer in line with the object. This happens if the observer is right-handed; if he is left-handed, he directs with his left eye. A right-handed person is also right-eyed and in daily life we ignore, no doubt unconsciously, the images of the left eye when they fall on retinal points that are not identical with the points stimulated in the right eye. This ignoring of images is so thoroughly done, that some people find it impossible to see the double image of a near object when the eye is fixed upon a far object.

Experiment 45. While looking at an object, press the right eye-ball out of place; the object appears double. When one eye-ball is moved out of its normal position, the image of the object no longer falls on the yellow spot of this eye; and as the image in the other eye does fall on the yellow spot, non-corresponding points of the two retinas are stimulated.

Experiment 46. While looking at an object place a prism before one eye. The object appears double. The reason for this is obvious if you bear in mind what was said under experiment 43.

We could thus multiply experiments supporting this theory of corresponding points, but time will not allow. In passing, I may mention that people who squint always see things double. The movements of their eyes are not coordinated; when one eye looks directly at any object and therefore has the focus of that object on the yellow spot, the focus of that object in the other eye does not fall on the yellow spot. Such people learn to neglect one of the images; but if a normal person should suddenly acquire strabismus by paralysis of the third or sixth cranial nerve, he would be seriously troubled by the resulting diplopia. No doubt you have noticed that drowsiness is generally associated with double vision; this is due to the lack of coordination in the movements of the two eyes, so that a slight squint results. In the same way we are able to explain the double vision of intoxication.

The question naturally presents itself, why does the stimulation of identical points cause single vision. To this question there is no satisfactory answer. It is assumed by some that it is due to the partial crossing of the optic nerve-fibers in the chiasm. From Fig. 21 it will be seen that the fibers from the left half of both the right and the left retina proceed to the left cerebral hemisphere. If the fiber which originates in a certain spot of the left retina ends at the same cerebral cell as the fiber from the corresponding

spot of the right retina, then we can readily understand how single vision must originate when these two points are simultaneously stimulated by the images of the same object. But, as I said, this is almost altogether an assumption.

Are any objects whose images do not fall on the yellow spots, and which we therefore see by indirect vision, seen single? That there are is shown in—

Experiment 47. Hold a pencil in the position indicated in Fig. 50 and look at the middle of the pencil (at a). Both

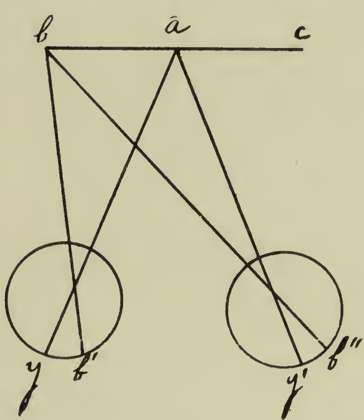


Fig. 50

ends of the pencil are then perceived by indirect vision, the images fall not on the yellow spots but on peripheral portions of the retina, yet you perceive each end of the pencil as a single object. The reason for this, according to the theory of identical points, is as follows:

In Fig. 50 the images of the point a, upon which the vision is fixed, fall upon the yellow spots y and y^1, hence this point is seen by direct vision, is seen most clearly and gives rise to only one impression. The end b of the pencil has its images at b^1 and b^{11}. These two points lie in the same direction and at approximately the same distance from y and y^1 and are therefore identical points; hence b is seen

single. The same is true for every point in the pencil, consequently the whole pencil is seen as a single object.

It is held that when the eyes are fixed upon a point at the horizon (primary position of the eyes) all points in the plane coinciding with the ground give rise to single impressions. This is known as the horopter.

Let us now suppose that two corresponding or identical points are stimulated simultaneously by images of two different objects. What is the result? Is there a fusion into one sensation? Generally not. There is a retinal rivalry, a struggle of the visual fields, as can readily be seen from

Experiment 48. With one eye look at a yellow card and with the other at a blue card; this can best be done by means of a stereoscope. Now we have seen in experiment 23 that if yellow and blue are simultaneously thrown into one eye, the result is white; that is, there is a fusion of sensations. This, however, does not take place when one eye is stimulated by yellow and the other by blue. The observer now sees yellow and now blue; there is a struggle between the two retinas for supremacy.

The image formed on the retina is a flat image, it has length and breadth but no thickness, yet in interpreting this image we ascribe solidity or depth to it. When, for instance, we view a landscape, we see this in its proper perspective, and find no difficulty in telling near from remote objects. As the image on the retina is formed on a plane and has no depth, it is evident that this knowledge of solidity cannot be derived as such from the image in the manner it gives us information of the length and breadth of the object; this knowledge is the result of many factors. Some of the factors that determine stereometric vision are monocular, some are binocular. We shall first discuss those factors that are monocular in origin.

1. Aerial Perspective. The atmosphere is not a perfectly transparent medium; dust and fog particles enveloping distant objects render them indistinct. Whenever an object

is thus seen, we judge it to be situated at a great distance, whether this be its true position or not. In a fog a near object looms very large because the indistinct and hazy image causes us to think of it as being placed at a great distance; but as the image on the retina is large, we over-estimate the size of the object. In a very clear atmosphere, as in mountainous regions, distant objects are not as hazy as at sea level, and hence these objects appear nearer and smaller than they are in reality. Beside this aerial perspective there is a

2. Mathematical Perspective. The retinal images of parallel lines are not parallel, but converging. When we stand between the rails of a railway, the rails seem to converge and meet in the distance. This convergence is interpreted by us as associated with greater distances. The artist makes use of this mathematical perspective to give solidity and depth to his drawing. If he represents lines that are parallel in nature as parallel in his painting, we say the painting lacks perspective and looks flat.

3. With one eye we can tell whether a given object is nearer than another object by the amount of accommodation necessary to bring a sharp image on the retina. By means of the muscle-sense we are able to tell whether the ciliary muscles of the eye are more or less contracted. But this is true only for objects situated quite close to the eye and even then it is of doubtful value. If the size of the objects is not known and the objects have a perfectly uniform appearance, that is, have no grain or other surface marks, it is almost impossible to tell which of the two objects is the nearer.

4. In a complex retinal picture, like that of a landscape, we judge of the distance of various objects by their relative size and thus obtain a sensation of solidity even with one eye. The artist makes use of this also; in the foreground of the picture he places an object of known size, such as a man or animal. By comparing the size of the distant ob-

ject with that of the object in the foreground, we arrive at an idea of the distance of the remote object.

Although we can to a certain extent perceive the solidity of objects with one eye, yet it is a well known fact that

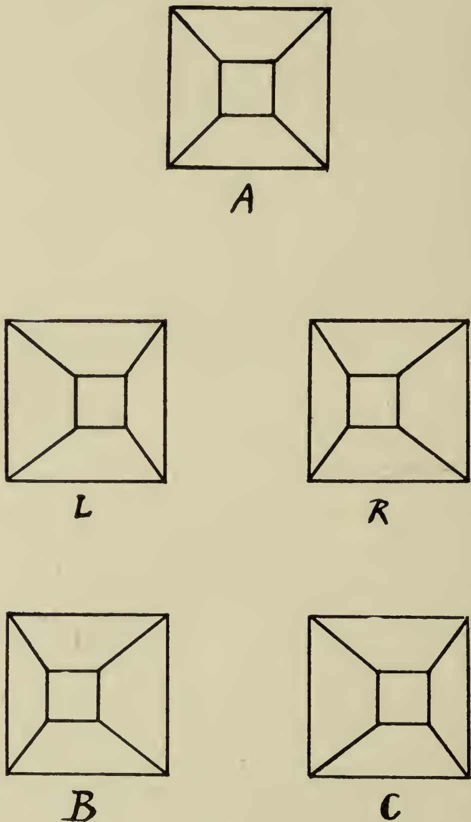


Fig. 51

depth value is more readily obtained with two eyes. The reason for this is sought in the difference between the image on the right and on the left retina. When you look at a book lying on the table, you see more of the right side of the

book with the right eye and more of the left side with the left eye. That is, the two images are not exactly the same.

If one views a truncated pyramid (A, Fig. 51) with the right eye, the image in this eye is like that shown in R (Fig. 51); viewed with the left eye, the image is like that repre-

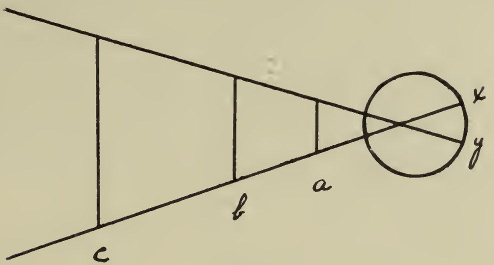


Fig. 52

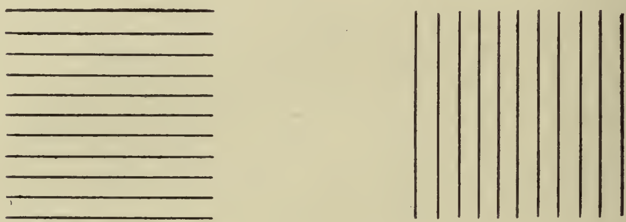
sented in L. If now you simultaneously cast L upon the left and R upon the right retina, you see the truncated pyramid stand out in relief, the small square in the figure projecting toward the observer. This can readily be done by means of a stereoscope. In making a stereoscopic picture, the two pictures are taken from two points of view separated by a distance equal to the distance between the right and left eye. The left-hand picture of the stereoscopic

Fig. 53

view represents the objects as they are seen by the left eye, and right-hand picture, as seen by the right eye. By means of prismatic lenses the right-hand picture is thrown upon the right retina (the screen in the median plane prevents it from falling upon the left retina) and the left-hand picture is thrown upon the left retina. This is, therefore, the same condition as obtains in nature when the two eyes view the actual objects, and the result must be the same, that is, the objects possess solidity.

By a little practice one can do this without the aid of a stereoscope.

Experiment 49. Look at L and R of Fig. 51, but instead of fixing your gaze upon them, look through the page as if you were looking at a distant object through a piece of glass. In this manner four images are obtained (diplopia) because the images of the figures do not fall on identical points. If now the eye-balls are converged, as in near vision, the two central images overlap and the pyramid stands out in relief. At first this experiment may prove a little difficult, but the result is so striking that it is well worth the effort.



A *B*

Fig. 54

So delicate is this process that by means of it we can distinguish between a genuine and a forged banknote. Two impressions of the same plate when seen through a stereoscope produce no sensations of depth, the letters and figures in both copies coincide exactly. But if a letter of the one copy is placed a trifle to the right or left with reference to the same letter in the other copy, when seen with a stereoscope, it appears to be situated in front or behind its mate.

What happens if the two pictures are reversed, that is, if R in Fig. 51 is thrown into the left and L into the right eye? In that case the near object appears more distant and the remote object nearer; in other words, a hollow trun-

cated pyramid with its base turned towards the observer is seen. This can be proven experimentally in B and C of Fig. 51.

The question still remains why do we ascribe solidity to an object when the images fall upon the retinas in the manner here described. To this question no satisfactory answer can be given. Some hold that the sensation of depth seen in a stereoscopic picture is due to the muscle-sensation caused by the contraction of the internal recti muscles which

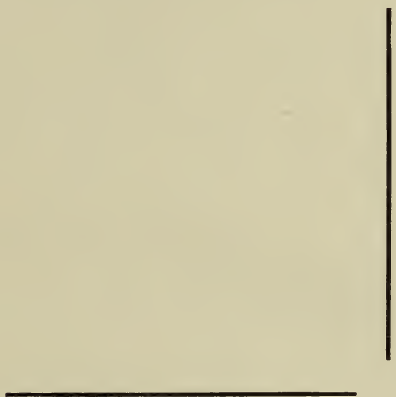


Fig. 55

converge the eyes. For a near object these muscles must be contracted to a greater extent than for a remote object and as we are conscious of the extent of this contraction, we can thus judge of the distance of an object. This, however, is not a satisfactory explanation, for a stereoscopic picture gives rise to the sensation of solidity when it is illuminated by an electric flash of such a brief duration that no muscle contraction could take place.

Seeing is a process of reasoning; a child must learn to see. A great many factors must be combined before all the sensations can be properly interpreted. This is well seen in children born blind and relieved in after-life by an opera-

tion. Cheselden records the case of a blind boy who after the operation could by mere sight not tell which was the cat and which the dog, although he knew them by feeling. He caught the cat and while feeling looked at her intently and said, "So. Puss, I shall know you another time." In another case the person was unable to discriminate between the picture of an object and the real object; it was only after

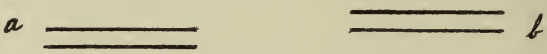


Fig. 56

the object and its picture had been seen and handled a great many times that he learned to distinguish them by sight. Yet the retinal images of the object and its picture were exactly the same as in a normal person; he lacked not the sensation of sight but the ability to interpret the sensation. There was not that knowledge which we derive from simultaneously seeing and touching the objects. Somebody has well defined seeing as feeling at a distance.

In our remarks about solidity we have already referred to our ability to judge of distance. In objects situated at a great distance from the eye, aerial perspective plays a great part. For this reason distant parts of the landscape seem

Fig. 57

nearer and smaller in wet than in dry weather; the dust of the atmosphere increases the aerial perspective and because of this haziness the objects are judged to be situated at a greater distance than they in reality are and therefore the size of the objects is also over-estimated.

The size of the retinal image is used in our judgment of distance; if the image is that of a known object, we can

quite accurately estimate the distance between us and the object, but if the size of the object is not known it may lead to gross error. The reason for this can be gathered from Fig. 52. The objects a, b, and c all have the same sized image (xy) on the retina. If I know the size of a, but not that of b or c, I might conclude that all three objects are at the same distances from the eye. Suppose c is a cow and suppose a is a cat; the images of both animals are of the same size, but as I am familiar with the size of these animals, I conclude from the size of the images that the cow is much further away than the cat. How misleading this can be is seen from the story of the farmer who

Fig. 58

called for his gun to shoot a chicken-hawk when he saw a fly crawling on the window. He was looking at the sky and mentally placed the fly at this great distance and therefore greatly over-estimated its size. As he was not focussing for the fly, the image on the retina was blurred; all this aided him in his delusion.

We have already alluded to the fact that it is extremely difficult to judge of distances with one eye.

Experiment 50. Close one eye and attempt to thread a needle held at a distance of about eighteen inches. It will be found no easy task, especially if the distance of the needle is varied. An interesting variation of this experiment is as follows: Make a small mark on a piece of paper lying on the table. Close one eye and try to strike the mark with the end of a pencil. What is extremely easy with two eyes becomes difficult if one eye is closed.

That our judgment of size is governed by our idea of distance is evident from the projection of the negative after image.

Experiment 51. Look at a distant window for some time so as to obtain a negative after image. When you think this has been obtained, look at a piece of paper held within a foot from the face; the image of the window looks small. Now look at the ceiling or distant wall and a large image of the window is seen. Yet the image of the window in the

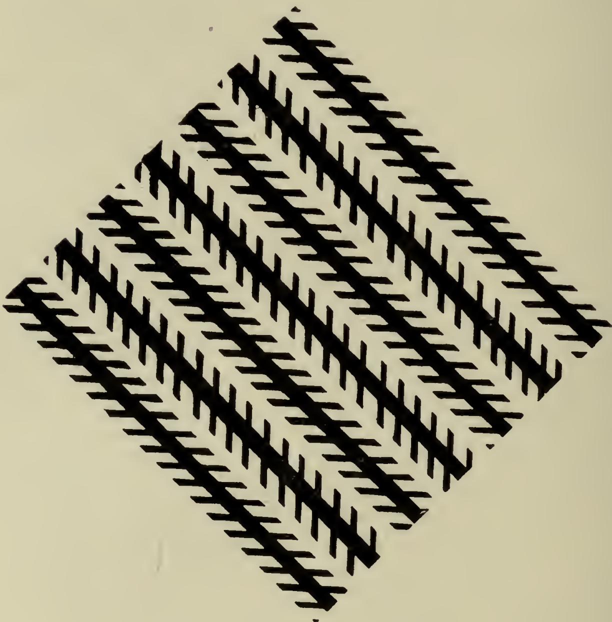


Fig. 59

eye is of the same size in both cases; our conception of size depends largely on the distance to which we project the sensation.

Our judgment of distance is greatly modified by many other factors. To most people the distance from b to c in Fig. 53 appears greater than that from a to b, yet they are equal. We can judge more accurately of the distance between two points when several objects intervene; a lands-

man is a poor judge of distances at sea. The moon at the horizon appears larger to us than when at the zenith; the many intervening objects between us and the moon when it is at the horizon give us an idea of greater distance and therefore of greater size. For this reason also we think of the sky as a flattened dome. When we were boys we amused ourselves by viewing the landscape or street with our head between our knees. Because of the nearness of the objects

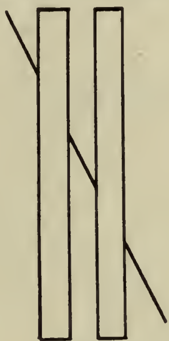


Fig. 60

in the foreground, which are neglected when we are in the erect position, we judge of the further objects as situated at an immense distance.

In judging of the distance between b and c in Fig. 53, we mentally add the smaller distances between the intervening points and the result is greater than when the mind must grasp the whole distance between a and b at one jump. In Fig. 54 the height of A appears greater than its length, while the reverse is true for B. That A and B are perfectly square and of the same size is hard to believe. It may also be stated that the space between A and B is of the same size as A or B, although it appears considerably smaller. The reason for this optical illusion is complex. First, we have this mental summation; we add the several vertical distances in A and hence it appears higher than it is long and also higher than B. Again, we always over-estimate vertical

length; the vertical line in Fig. 55 appears longer than the horizontal line. For this reason the difference between the height and the length of A is greater than the difference between the height and length of B. There is a third reason. In Fig. 56 the two lines, a and b, do not appear to be on a level; a appears to be situated higher up than b. The presence of the line below a raises a and the line above b depresses b. This is also true for the horizontal lines in A, Fig. 54; they seem to force each other apart and thereby increase the height of A.

Another factor that greatly influences our judgment of distances and size is the presence of angles. In Fig. 57 the

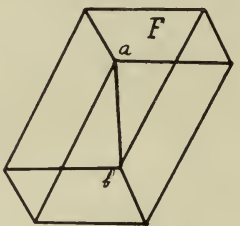


Fig. 61

line a is judged to be longer than the line b. Similarly it is difficult to believe that the line B in Fig. 58 is no longer than the line A. Because of the presence of the short diagonal lines in Fig. 59, the heavy black lines seem to diverge and converge alternately. The degree of convergence and divergence depends to a large extent upon the position of the parallel lines. If the book is held in such a position that the long lines in Fig. 59 are vertical, the lines appear more nearly parallel; this is still more evident if the lines are held horizontally.

For this reason also the three short oblique lines in Fig. 60 do not seem to lie in a straight line; the middle piece seems to be placed lower than the upper and higher than the lower piece. This illusion also disappears to a large extent if the line is held horizontally.

In conclusion I may call your attention to another optical deception. In Fig. 61 we have Necker's parallelopiped. When the corner a is viewed, the parallelopiped generally seems to lean towards the observer and the end F faces him. After looking at the figure for a few moments, especially when the point b is fixed upon, the figure seems to change and the parallelopiped leans away from the observer. Still more beautifully is this illusion brought out in Fig. 62. If this figure is looked at it may be seen either as two cubes

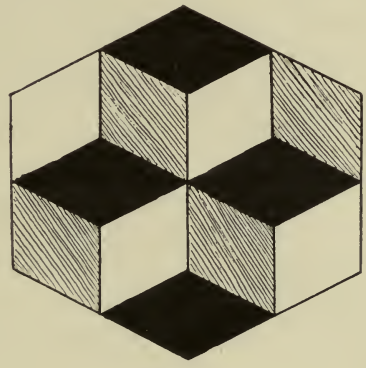


Fig. 62

resting upon another cube with the under surfaces dark, or as one cube resting on two cubes with the upper surface dark. The mathematical perspective is such that both interpretations are possible.

From all this it is very evident that seeing, by which we mean the interpretation of the various sensations, is an extremely complicated process and one that may frequently lead us to false conclusions, so that it is often a question whether or not we can trust our own eyes.

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